UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

EVALUATION OF THE WILKESON-CARBONADO COAL FIELD, PIERCE COUNTY, WASHINGTON FOR HYDRAULIC COAL MINING

(In Two Parts)

Part One - Geology
Part Two - Water Resources

Prepared in cooperation with the Bureau of Mines

This report has not been edited or reviewed for conformity with U.S. Geological Survey standards or nomenclature.

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WILKESON-CARBONADO COAL FIELD,

PIERCE COUNTY, WASHINGTON

FOR HYDRAULIC COAL MINING

Part one - Geology

GEOLOGIC EVALUATION OF THE WILKESON-CARBONADO COAL FIELD, PIERCE COUNTY, WASHINGTON, FOR HYDRAULIC COAL MINING

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Prepared by the Branch of Coal Resources, Denver, Colorado, 1977

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SUMMARY

This report includes a review and analysis of the relevant geological information that is available on the Wilkeson-Carbonado coal field in Pierce County, Washington.

The coal deposits are in the Puget Group of Eocene age, which has been intensely folded and faulted, and in places intruded by igneous rocks. Much of the coal-bearing sequence is concealed by glacial deposits and a dense forest growth, so exposures of bedrock are rare. Detailed geologic knowledge of the coal-bearing sequence is confined to areas of extensive mining, and very little is known about the geology of the intervening areas or the relation of the geology of one mine area to another. About 40 coal beds, which vary from a few inches to 23 feet in thickness, occur in a dominantly siltstone-sandstone sequence more than 8,000 feet thick. The Wilkeson-Carbonado coal field has significant reserves of metallurgical coal, probably 60 to 125 million tons. Most of the easily accessible coal has been mined, and part of the remaining estimated coal resources may be uneconomical to mine because of prior mining.

Coal in the Wilkeson-Carbonado coal field ranges in rank from high-volatile A bituminous to low-volatile bituminous. The coal in the beds in the upper part of the coal-bearing sequence is generally noncoking, however, coal in the lower part of the sequence has good coking qualities. The coal has a low sulfur content, generally less than 1 percent; the ash content is rather high, ranging from 8 to 23 percent. Most of the coal is fractured and brittle enough to be classed as friable. About 21 million tons of coal has been produced from the 12 beds that were workable under past market conditions.

Water supply and quality in the Carbon River and South Prairie Creek drainages appear to be adequate for hydraulic coal mining, assuming a recycled water supply. However, the selection of a site in the Wilkeson-Carbonado coal field for hydraulic mining experiments, or the possible development of a producing mine using hydraulic mining concepts, will require careful consideration of many adverse geologic conditions. The steeply dipping and fault terminated coal beds present many mining difficulties that will require ingenuity and resourceful engineering to make hydraulic mining a successful venture.

It is recommended that very detailed investigations of the geology and hydrology of the Wilkeson-Carbonado coal field be made prior to selection of a mine site and to verify the feasibility of hydraulic mining.

INTRODUCTION

Scope of Investigations

This report was prepared by the U.S. Geological survey in cooperation with the U.S. Bureau of Mines under USBM contract Number J0166209 of the Bureau's Advancing Coal Mining Technology (ACMT) Program. The report includes a summary and evaluation of geologic and mining data available on the Wilkeson-Carbonado coal field of Pierce County, Washington. This is the first in a series of reports to be prepared by the Geological Survey relating to one of five geographic areas of pitching coal identified by the Bureau, for which further geologic information is needed before their potential for hydraulic mining can be adequately appraised. Subsequent reports in this series will cover four areas of pitching coal in Colorado.

The objectives of this investigation have included a review of existing geologic reports on the study area, an evaluation and synthesis of these data, and identification of geologic factors that would influence the recovery of the coal resources. Although this investigation is based primarily on a review of published literature, it also includes data collected by personal contacts and in the course of a brief field investigation made in April, 1977.

This report consists of two parts. Part one includes a discussion of the geologic setting, stratigraphy, structure, coal beds, resources, and past mining experience which was prepared by the Branch of Coal Resources within the Geologic Division of the U.S. Geological Survey. Part two of this report contains a discussion of surface and ground water conditions within the study area which was prepared by the Groundwater Division of the Geological Survey at the request of the Branch of Coal Resources.

Location and Geologic Setting

The Wilkeson-Carbonado coal field contains the only sizeable resources of coking coal in the Pacific Coast States. The field is situated in the north central part of Pierce County in southwestern Washington and is roughly bounded by meridians 122° and 122°5' W., and parallels 47° and 47°10'N. Figure 1 shows the location of the Wilkeson-Carbonado coal field and its relation to other coal-bearing areas in Washington. The coal field is a rectangular-shaped area of about 35 square miles on the west slope of the Cascade Range about 18 miles southeast of Tacoma, and about 30 miles south-southeast of Seattle. The field is named after the two largest communities, Wilkeson and Carbonado, within the limits of the coal-bearing sequence, but also includes the mines at Burnett, Spiketon, Willis, Melmont, and Fairfax (fig. 2). The coal-bearing sequence is probably continuous across concealed areas south of Fairfax and is thought to extend to Ashford, about 18 miles south of Fairfax. The area south of Fairfax is collectively known as the Puyallup-Ashford field (Daniels, 1914, p. 9).

The coal deposits of the Wilkeson-Carbonado field occur in the Puget Group of Eocene age (Gard, 1968, p. B5) and are confined to a narrow belt about 3.5 miles wide extending 9.5 miles northward from Upper Fairfax to a point just south of Buckley. On the east side of this belt the coal-bearing rocks dip beneath volcanic clastic rocks of Oligocene age. Along the west side of the belt the upper coal-bearing part of the Puget group thins to extinction (Gard, 1968, p. B12) and the lower coal-bearing part of the Puget Group dips west below a thick sequence of volcanic breccia, tuff, and volcanic sandstone and conglomerate of Upper Eocene age.

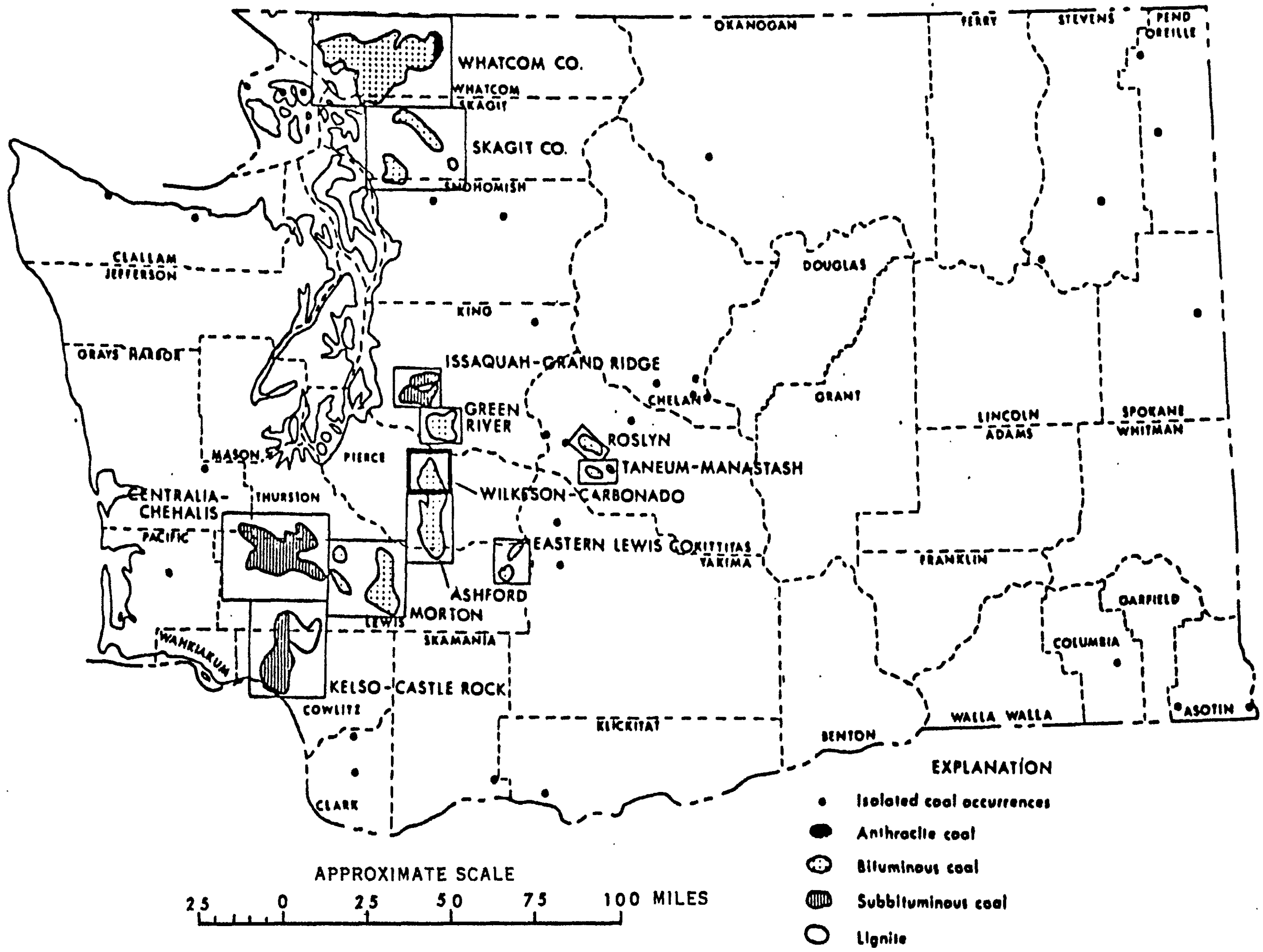

FIGURE 1.--Index map of Washington showing area of this report (bold outline) and its relation to other coal-bearing areas (modified from Livingston, 1974, figure 1).

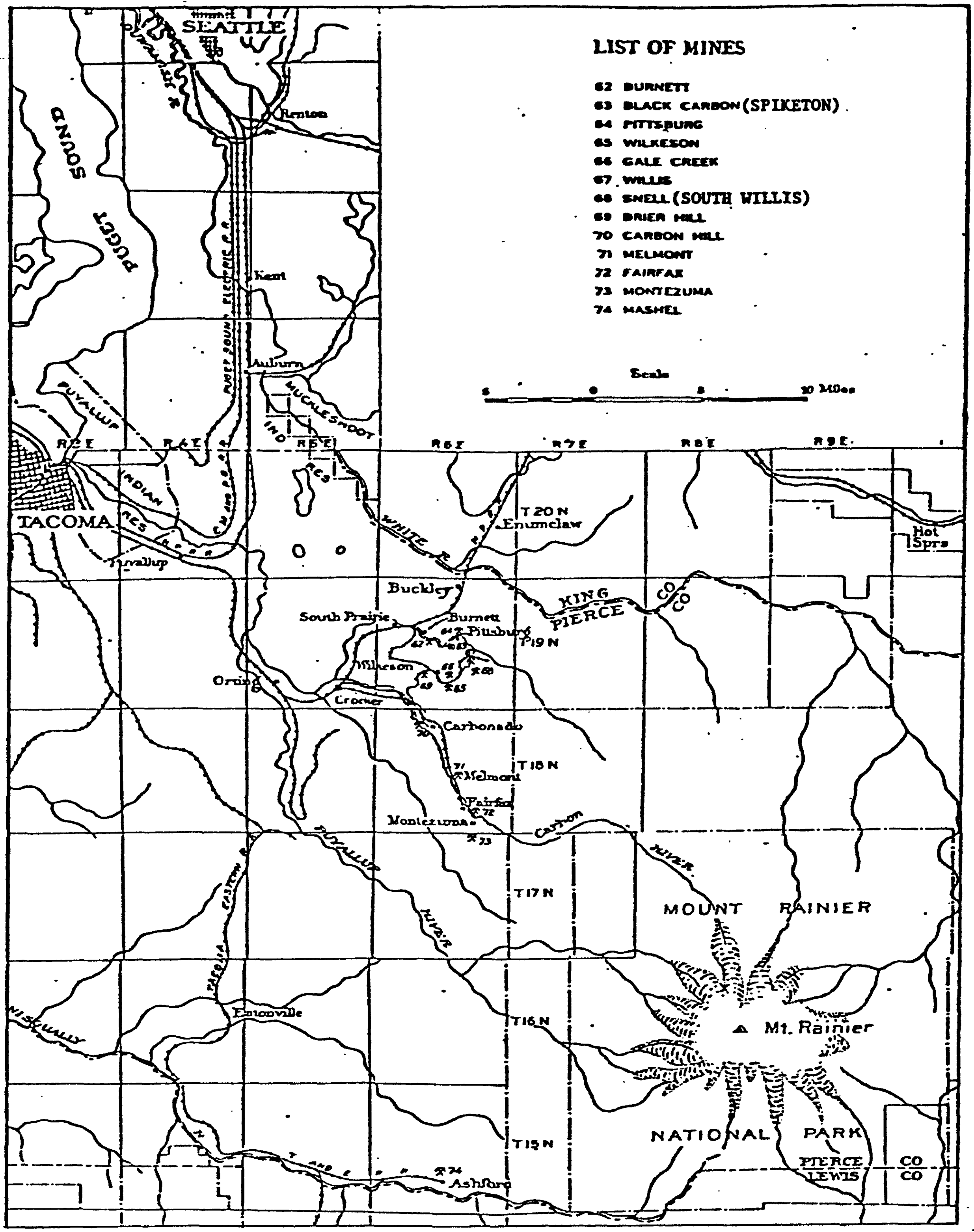

FIGURE 2.--Map showing location of mines in Wilkeson-Carbonado area. (modified from Smith, 1911, plate 3)

Much of the coal-bearing sequence in the Wilkeson-Carbonado field is concealed by thin to thick deposits of glacial drift and a dense forest growth. The coal-bearing strata have been intensely folded and faulted. Most of the folds are narrow asymetrical, north-northwestward trending structures, the principal fold being the Wilkeson anticline. Average dips on the flanks of the folds are generally about 60°. The strata are cut by many high-angle reverse and normal strike faults most of which are subparallel to the fold axes and others which are generally normal faults that transect and postdate the strike faults (Gard, 1968, p. B26). Displacement along the faults ranges from a few feet to 1,800 feet. Dikes sills, and small plugs of intrusive igneous rocks, which are encountered within the coal-bearing sequence, locally have had a marked effect on the character of the coal. The coal ranges in rank from high-volatile A bituminous to low-volatile bituminous. The rank of the coal, however, results from the intense structural deformation in the area and not from the igneous intrusives. Coal from the lower part of the Puget Group can be coked.

About 21 million tons of coal have been produced from the field and annual production reached a high of 832,272 tons in 1913. Production declined thereafter, having dwindled to less than 1,000 tons in 1959. There are no operating mines in the field at this time (1977).

Because of paucity of exposures in the area, knowledge of the coal deposits is limited chiefly to areas of extensive mining and very little is known about the intervening areas between mines or the relation of one area to another.

Previous Investigations

Coal was first discovered in the Wilkeson-Carbonado field in the canyon of the Carbon River about 1862 and the first mine was opened in 1874 (Daniels, 1914, p. 60). During the Northern Transcontinental Survey, made by the U.S. Geological Survey in 1881-1884, the pioneer work on the coal deposits of Washington was done by Bailey Willis and the summary of the results of this survey were reported in the Tenth Census Report of the United States (1886) and in the 18th Annual Report of the U.S. Geological Survey (1898). Willis and G. O. Smith (1899) continued investigations and included a description of the coal measures and a structure map of the Wilkeson-Carbonado coal field in their description of the Tacoma quadrangle. Smith (1902) later reviewed the structure and economic development of the coal fields.

In 1909-10, E. E. Smith (1911), of the U.S. Geological Survey, examined, sampled, and analyzed coals of the entire State of Washington in a cooperative program with the Geological Survey of Washington. Analyses of coals from the Wilkeson-Carbonado field are also available from Fieldner and others (1931), Cooper and Abernethy (1941), Abernethy and others (1958), and Matson and White (1975).

The most comprehensive report on the Wilkeson-Carbonado coal field was prepared by Joseph Daniels (1914). Daniels examined all of the operating mines, studying the underground relations and structure of the coal field, and measured many stratigraphic sections in the mine workings. His report included a correlation of the coal beds that were being worked at that time. Later Ash (1931), on the basis of new information, extended the correlation of coal beds over a wider area and proposed a new system of coal bed nomenclature. Weaver (1937) measured and published a stratigraphic section of part of the coal-bearing sequence exposed in the Carbon River Gorge.

The U.S. Bureau of Mines and others have published numerous reports covering coking processes and the carbonizing properties of coals produced from the Wilkeson-Carbonado field. Among these are: Belden and others (1910), Daniels (1920), Marshall and Bird (1931), Yancey and others (1932), Yancey and others (1939), Daniels (1941), Davis and others (1942), Yancey and others (1943), and Davis and others (1952).

Washability studies and cleaning trials on coals from the Wilkeson-Carbonado field have been reported in McMillan and Bird (1924), Bird and Marshall (1931), and Geer (1964). Coal mining problems and systems of coal mining in the Wilkeson-Carbonado field were discussed by Evans (1924) and Ash(1925).

The most recent geologic investigations of the Wilkeson-Carbonado coal field and adjacent areas were made by Crandell and Gard (1960), Crandell (1963), and Gard (1968). Their series of reports provides well-documented descriptions of the surficial geology, geomorphology, and bedrock geology of the Lake Tapps quadrangle, including the area of the coal field. Detailed information on the coal resources of the Wilkeson-Carbonado field is contained in the state summary of coal reserves prepared by Beikman, Gower, and Dana (1961, p. 63-85). Livingston (1974, p. 51-54) also summarized coal thickness, analytical, and resource data of the study area. The reserve base of coal for underground mining is categorized in Matson and White (1975).

An economic feasibility study of the coal producing area was prepared under the supervision of the U.S. Bonneville Power Administration in 1963.

Data Acquisition and Acknowledgements

Data for this investigation was acquired primarily from the literature. The comprehensive reports of Daniels (1914), Beikman, Gower, and Dana (1961), and Gard (1968) supplied much of the information presented in this report. The authors thank L. M. Gard, Jr., of the U.S. Geological Survey for the use of some original field notes and for providing mine maps and other unpublished data, which yielded valuable information .

The authors visited the study area between March 29 and April 7, 1977, during which time the cooperation of E. R. Vonheeder, Geologist, Division of Geology and Earth Sciences, Washington Department of Natural Resources, and D. B. Hume of Donald B. Hume and Associates facilitated the work, as did the friendly assistance rendered by N. R. Welch and Doris Smith of the U.S. Bureau of Mines, Olympia, Washington.

GEOGRAPHY

Topography and Drainage

The Wilkeson-Carbonado coal field occurs principally in an upland area at an altitude of 1,100 feet to about 2,300 feet. The field is in part of the foothills of the Cascade Range, and is bordered to the north by a broad rolling lowland at an alititude of 400 feet to 1,100 feet that is part of the Puget Sound lowland. The total relief within the area of the coal field is about 1,830 feet; the highest point in the field is on the crest of Gleason Hill at an altitude of 2,307 feet. The lowest point within the field is 480 feet near Cascade Junction at the confluence of South Prairie and Wilkeson Creeks. Topographic quadrangle maps of the Wilkeson and Buckley quadrangles, which cover the area of the coal field, are included for reference purposes in the Appendix of this report.

In general, the area of the coal field is characterized by a rather flat, northwest-sloping surface that has been deeply dissected. The present topography and drainage are the result mainly of erosion and deposition during Pleistocene time, Quaternary deposits mask an older topography carved on the bedrock surface (Gard, 1968, p. B3).

The master stream of the area is the Carbon River which heads in a glacier about 15 miles southeast of the study area. The river has cut a deep valley through the coal field. The valley is fairly wide where the river enters the southeastern part of the coal field (fig. 3) and narrows a few miles downstream where the river cuts through more resistant bedrock and forms the Carbon Gorge. At Fairfax Bridge the gorge is nearly 900 feet deep and only slightly more than 1,000 feet wide (fig. 4). The sides of this gorge form the most precipitous slopes in the area and at places between Fairfax Bridge and Carbonado the walls are vertical to overhanging (Gard, 1968, p. B4). About 3 miles downstream from Carbonado the river emerges from the bedrock gorge and occupies a broad steep-walled valley formed chiefly in surficial deposits.

FIGURE 3.--Carbon River southeastward from Upper Fairfax, sec. 35, T. 18 N., R. 6 E.

FIGURE 4.--Carbon River Gorge northward from Fairfax Bridge, sec. 16, T. 18 N., R. 6 E.

The eastern and northern parts of the coal field are drained by South Prairie Creek and its tributary, Wilkeson Creek (formerly called Gale Creek) both of which head in the Cascade Range. Gale Creek, a tributary of Wilkeson Creek, drains the east central part of the area, and Lily Creek, a tributary of the Carbon River drains the southwestern margin of the coal field.

Climate and Vegetation

The Wilkeson-Carbonado coal field and surrounding territory have a somewhat modified marine climate. Prevailing westerly winds heavily-laden with water vapor after their passage over the Pacific, rise to pass over the Olympic Range to the west of the area, and cooled at higher altitudes, they drop heavy rains on the windward slopes. Warming as they descend the leeward slopes. they hold their moisture until they meet the Cascades to repeat the wet-dry cycle.

Summers are generally cool and dry, and winters are mild and wet. The mean annual temperature is about 46°F. Precipitation at the lower latitudes is principally rain. Both rainfall and snowfall increase with an increase in altitude from the northwest to the southeast. The total annual precipitation in the vicinity of Carbonado averages about 75 inches. Almost 70 percent of the yearly precipitation falls during the 6-month period from October to March (table 1).

TABLE 1.--Total precipitation (inches) measured at Carbonado weather station by month and year, 1951-60 (U.S. Weather Bureau, 1965)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANN
						CARBONADO 8 SSE							
1951	10.24	10.84	7.21	.89	4.75	1.37	.25	1.79	4.32	10.68	9.06	7.08	68.48
1952	4.32	5.79	5.37	4.33	3.97	3.91	.52	1.13	1.38	1.79	.86	5.91	39.28
1953	20.20	5.80	5.40	E 6.26	E 5.25	6.22	2.52	3.20	4.01	4.75	E 9.69	-	-
1954	-	-	-	-	5.22	7.16	3.12	4.15	3.53	5.71	9.04	8.42	-
1955	4.09	7.72	E 7.71	7.37	4.37	4.52	2.92	.17	4.22	13.55	E11.79	E14.43	82.86
1956	-	-	-	-	-	-	.85	2.19	-	9.91	3.97	-	-
1957	-	-	-	-	-	3.79	1.65	1.58	2.85	7.15	-	-	-
1958	9.69	9.70	3.78	9.54	2.38	5.52	.00	1.31	4.35	6.77	10.50	12.88	85.42
1959	13.31	5.27	8.44	6.93	7.06	7.21	1.38	2.41	8.68	11.50	14.62	8.12	94.93
1960	3.61	7.31	5.74	6.55	13.33	3.88	.04	5.43	2.98	8.76	13.76	4.87	76.26
PERIOD	9.35	7.49	6.24	5.98	5.79	4.84	1.33	2.34	4.04	8.06	10.25	8.82	74.53
YEARS	7	7	7	7	8	9	10	10	9	10	9	7	
RECORD	7.68	6.91	6.73	5.81	4.95	4.79	1.84	1.99	3.88	7.26	9.49	10.78	72.11
YEARS	22	22	22	23	28	29	30	30	28	30	25	22	

8 SSE-distance (miles) and direction from post office.
E-estimated or interpolated from nearby stations.
A dash indicates missing or insufficient record.

Dense forests of fir, spruce, cedar, and hemlock that once covered this area were logged off early in this century. Much of the Cascade foothills is now a tree farm and is covered with large stands of second-growth hemlock, fir, and spruce. Madrona grows in the better drained areas, and dense stands of red alter are found wherever there has not been artificial reforestation. Big-leaf maple and western redcedar are common in the lower moister areas.

Population and Ownership

The largest communities in the coal field are Carbonado (population 394) and Wilkeson(population 317). Buckley (population 3,446), which is located just north of the coal field, is the largest community in the general area. Sites of several abandoned coal-mining towns, which owed their inception to the coal-mining industry, are now marked by a few buildings or, more commonly, by only foundations and ruins overgrown by brush. These old towns include: Spiketon, also known as Black Carbon and as Pittsburg, which was adjacent to South Prairie Creek in the SE 1/4 sec. 15, T. 19 N., R. 6 E., east of Burnett; South Willis, which was in SE 1/4 sec. 22, T. 19 N., R. 6 E., northeast of Wilkeson; Melmont, which was about 3 miles south of Carbonado in the E 1/2 sec. 21, T. 19 N., R. 6 E., along the abandoned railroad on the east side of the Carbon River; and Montezuma, now known as Upper Fairfax, which is in the south-east corner of the study area.

Figure 5 shows a highly generalized map of the Wilkeson-Carbonado coal field (modified from U.S. Bonneville Power Administration, 1963, fig.2) on which ownership of the surface is shown by several classes of owners. The map was prepared from information available in 1951, but present ownership probably is not appreciably different. The coal field as outlined on this map (after Daniels, 1914, pl. 1) embraces a slightly larger area than is shown on the geologic map (pl. 1) accompanying this report, as it includes about 16 square miles of territory east of the 122°W. parallel in which the geologic relations have not been accurately determined.

Figure 6 shows the mineral rights (as of 1951) for most of the field by several classes of owners. In most cases mineral rights conform with surface ownership, but for some tracts they are held separately. The type of surface and mineral ownership in this field would not be expected to impede development of a mining operation (U.S. Bonneville Power Administration, 1963, p. 17).

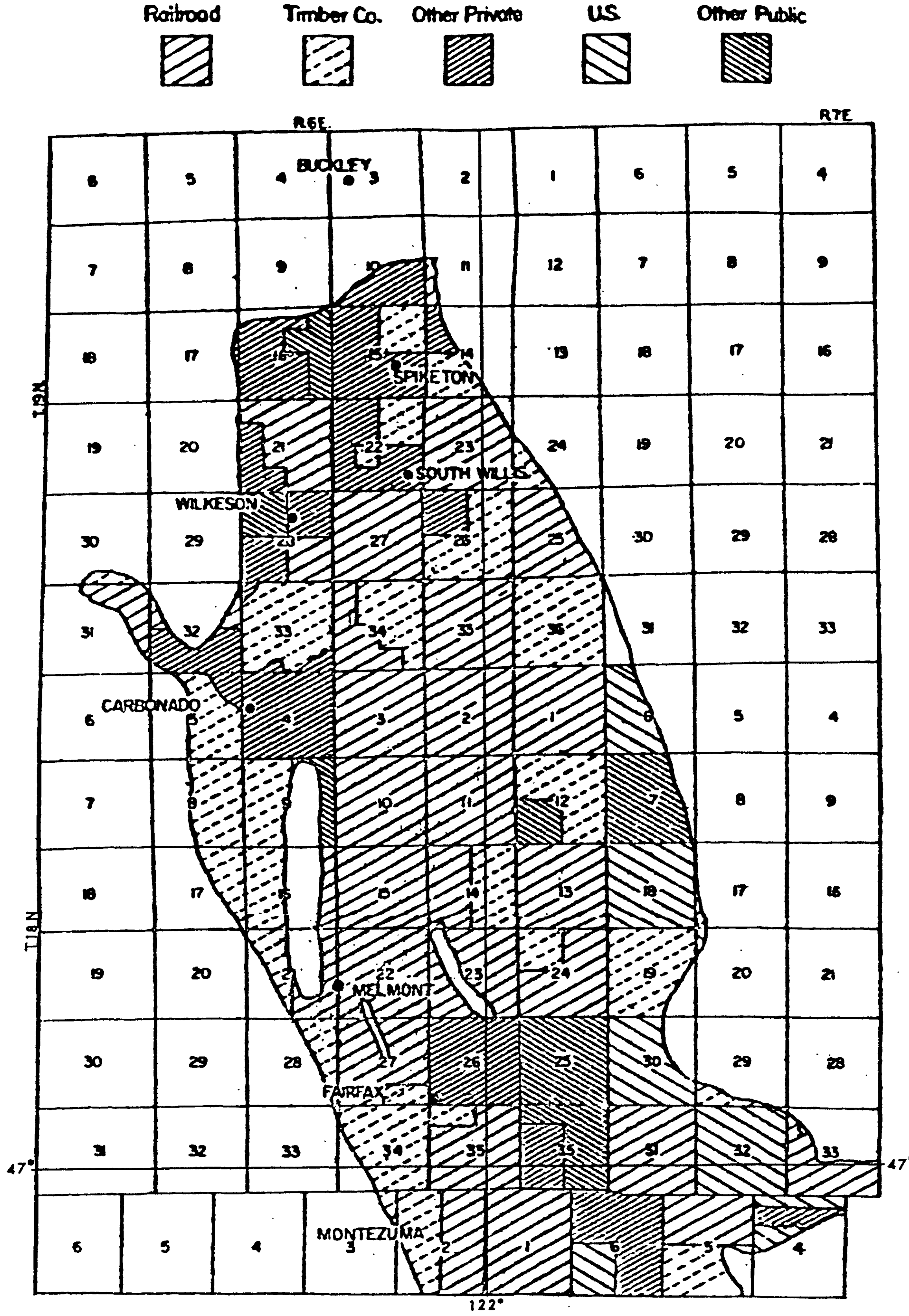

FIGURE 5.--Property ownership in the Wilkeson-Carbonado coal field (modified from U. S. Bonneville Power Administration, 1963, fig.2)

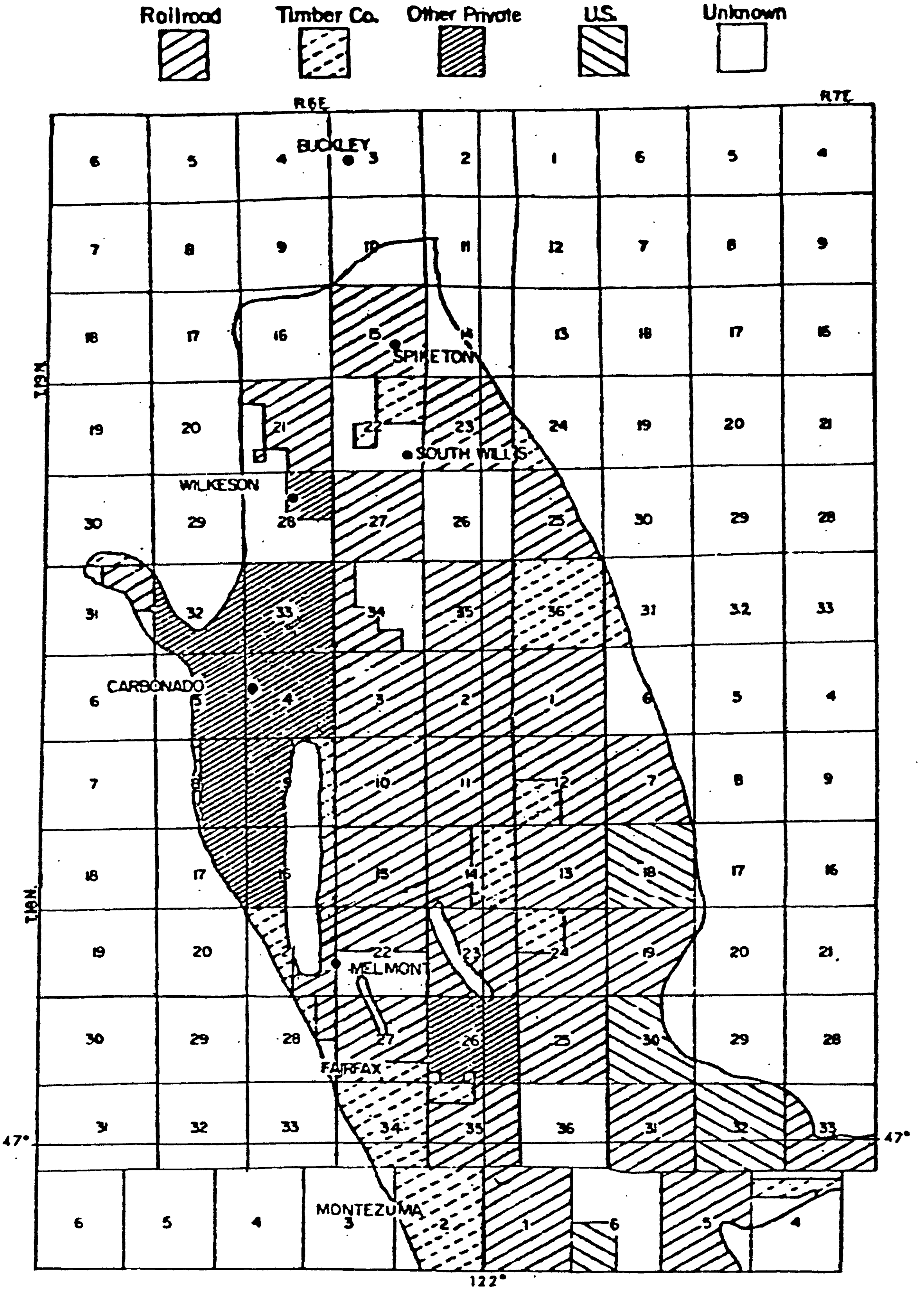

FIGURE 6.--Mineral rights ownership in the Wilkeson-Carbonado coal field (modified from U.S. Bonneville Power Administration, 1963, fig.3)

Accessibility

Access to the area ranges from good to poor. Some parts of the area are accessible only by private logging roads and roads maintained for fire protection. State Route 165, which trends southward from Buckley through Burnett, Wilkeson, and Carbonado, is the principal improved highway traversing the coal field. Graveled or dirt secondary roads provide access to most parts of the coal field. A branch of the Northern Pacific Railroad extends from South Prairie southeastward to Wilkeson and Carbonado.

STRATIGRAPHY

General Features

More than 8,000 feet of sedimentary and volcanic rocks of Early Tertiary (Eocene) age crop out in the Wilkeson-Carbonado coal field. These rocks form the coal-bearing Puget Group which is comprised of the Carbonado, Northcraft, and Spiketon Formations (Gard, 1968, p. B5). The Puget Group is overlain by volcanic sedimentary rocks and pyroclastic rocks of the lower part of the Ohanapecosh Formation of Oligocene age. The Puget and Ohanapecosh rocks are folded and faulted and were intruded by igneous dikes and sills of Oligocene(?) age or Miocene(?) age. After deformation and intrusion the rocks were uplifted and eroded. Semi-consolidated till and outwash from Quaternary (Pleistocene) glaciers and alluvium (Recent) were later deposited unconformably on the Puget and Ohanapecosh rocks in some places.

Tertiary System

Eocene Series

Puget Group

The Puget Group, a thick sequence of predominantly continental coal-bearing sedimentary rocks, is one of the most widespread stratigraphic units in the Pacific Northwest (Wolfe and others, 1961). These rocks underlie a large area in the western foothills of the Cascade Range and in the Puget Sound lowlands of western Washington. The Puget consists of Middle(?) to Upper(?) Eocene strata of fresh- and brackish-water origin that are locally interstratified with volcanic sedimentary rocks (Gard, 1968, p. B5).

The rocks of the Puget Group were first described by Willis (1886) and referred to as the "coal measures of the Puget Sound basin". These rocks subsequently were named Puget Group by White (1888) and were subdivided into the Carbonado, Wilkeson, and Burnett Formations in the Wilkeson-Carbonado area by Willis (1898).

Gard (1968, p. B5) noted that "the lithologic similarity of the strata in all the formations of Willis, as well as the scarcity of continuous exposures, renders these formations of limited use for mapping purposes and necessitates changes in nomenclature". Whereupon, he redefined the Puget Group in the Wilkeson-Carbonado area to include the Carbonado, Northcraft, and Spiketon Formations. The Carbonado Formation of Willis was redefined to include the beds of Willis' Carbonado and Wilkeson Fromations and the lower part of the Burnett Formation. Gard noted the presence of a thick to thin wedge of volcanic sedimentary rocks within the coal-bearing Puget Group which he correlated with the Northcraft Formation of Snavely and others (1958). The Spiketon Formation was defined to include the coal-bearing rocks that overlie the Northcraft Formation which comprise the upper 3,600 feet of Willis' Burnett Formation.

Carbonado Formation.--The Carbonado Formation consists of moderately indurated interbedded sandstone, siltstone, mudstone, shale, and numerous thin to thick beds of coal. The total exposed thickness is more than 5,000 feet along the Carbon River west of Carbonado (Gard, 1968, p. B6). The top of the formation is placed at the base of the volcanic sedimentary rocks of the Northcraft Formation. The base of the Carbonado is concealed and the total thickness of the formation is unknown.

The formation occupies a northward-trending belt about 3 miles wide through most of the study area that is best, though discontinuously, exposed on the South Prairie Creek near Burnett, on Gale Creek near Wilkeson, and on the Carbon River from sec. 31, T. 19 N., R. 6 E. upstream to Fairfax. The Carbonado Formation is characterized by lithologic variations and changes in thickness of bedding within short distances along strike. The formation is composed of light-gray to brown sandstone and gray to brown or black siltstone, mudstone, carbonaceous shale, and coal. Although sandstone makes the most conspicuous outcrops because of its resistant nature, it probably forms less than half of the total thickness of the formation (Gard, 1968, p. B8). The sandstone is composed chiefly of quartz (about 50 percent) and feldspar (about 35 percent); black chert, quartzite, mica, and rock fragments are common minor constituents. The cementing material of the sandstone appears to be mainly secondary calcite, although clay minerals probably also act as a binding agent (Gard, 1968, p. B7).

Sandstone strata are locally very thick bedded, commonly crossbedded, lenticular, and many lenses are probably channel fillings. Individual sandstone strata range greatly in thickness; some are only a few inches thick, others are as much as 100 feet thick.

The siltstone and mudstone beds in the Carbonado Formation are light brown, to black, depending on the amount of incorporated organic matter, grain size, and state of oxidation. They weather readily, so that outcrops are limited to artificial cuts and recently eroded streambanks. Individual beds in these fine-grained strata range from laminations a fraction of an inch thick to beds 25 feet thick. Alternating thin beds of siltstone, mudstone, and fine-grained sandstone form sequences as much as 100 feet thick.

Carbonaceous shales and bony shales are fairly abundant throughout the Carbonado Formation. The carbonaceous shales are black, soft, and usually foliated (Daniels, 1914, p. 25). They are commonly associated with beds of coal as partings in a bed, and also commonly comprise the roof (hanging wall) and floor (footwall) rocks of coal beds.

Numerous beds of coal, bony coal, and bone are interbedded with other sedimentary rocks in the lower 3,000 feet of the Carbonado Formation exposed in the area, however, the upper 2,000 feet of the formation is virtually barren of coal. Carbonaceous beds commonly grade laterally and vertically into coal beds. The coal beds usually have sharp contacts with the overlying and underlying rocks and in some places the upper parts of some coal beds are cut by scour-and-fill channels. Coal beds in the Carbonado Formation are as much as 23 feet thick, although most are 2 to 8 feet thick. Twenty-two beds have been mined in the lower 3,000 feet of the formation in the area between Burnett and Fairfax.

Northcraft Formation.--The Northcraft Formation in the vicinity of the Wilkeson-Carbonado coal field consists of volcanic breccia and tuff and lesser amounts of volcanic conglomerate and volcanic sandstone. It is well exposed 3 miles west of the coal field where it is more than 2,000 feet thick. Its maximum thickness in the eastern part of the coal field is only about 200 feet.

The Northcraft lies at or near the surface in two northward-trending belts on both flanks of the coal field. On the east flank of the coal field the formation occurs in a narrow belt of poorly exposed rocks. Outcrops are limited to the valley walls of South Prairie Creek, the sides of the melt-water channel east of Wilkeson, and the hillside in the NW 1/4 sec. 35, T. 19 N., R. 6 E., southeast of Wilkeson. West of the coal field the belt of Northcraft outcrops is about 6 miles wide and can be traced for more than 20 miles from the Carbon River southward to the Nisqually River. In the southern part of the area these rocks are covered by Pleistocene deposits and the location of the contact with the underlying Carbonado Formation is inferred from exposures along the Carbon River and along the Puyallup River about 2 miles south of the map area (Gard, 1968, p. B9).

In the eastern part of the Wilkeson-Carbonado coal field, where the Northcraft is thin, it is overlain by the coal-bearing Spiketon Formation; but on the west margin of the coal field, where the Northcraft is considerably thicker, the Spiketon Formation is absent.

The Northcraft Formation is composed mainly of somber-hued volcanic breccia of andesitic composition. The rocks are generally brownish or yellowish black but on fresh surfaces may be brick red, dark gray, greenish gray, or black. Most layers of breccia appear to have been emplaced as volcanic mudflows, but some may be breccias of pyroclastic origin or flow breccias (Gard, 1968, p. B9).

Spiketon Formation.--The Spiketon Formation is comprised of alternating beds of light-gray arkosic sandstone, gray to brown or black siltstone, mudstone, shale, carbonaceous shale, and coal that overlies the Northcraft Formation in the eastern part of the Wilkeson-Carbonado coal field. It is typically exposed along the valley walls of South Prairie Creek near the abandoned coal-mining community of Spiketon in SE 1/4 sec. 15, T. 19 N., R. 6 E. The formation is about 3,600 feet thick and includes the upper part of the Burnett Formation of Willis and Smith (1899, p. 8). It is overlain with apparent conformity by volcanic sedimentary and pyroclastic rocks of the Ohanapecosh Formation (Gard, 1968, p. B11-B12).

The Spiketon Formation lies at or near the surface in a northwestward-trending belt about three-quarters of a mile wide on the eastern margin of the coal field but is absent in the western part of the field. The formation crops out in secs. 14, 15, 22, and 23, T. 19 N., R. 6 E.; the most extensive outcrop of the formation is near the west edge of sec. 23.

The Spiketon Formation is lithologically indistinguishable from the Carbonado Formation, and the two can be separated only where the volcanic rocks of the Northcraft Formation are present. The main known difference between the Carbonado and Spiketon Formations is in the quality of the coal occurring in them. Coal in the Carbonado Formation generally cokes well and has an average heat value of 12,000 to 14,000 Btu per pound, whereas the coal of the Spiketon Formation generally cokes poorly and has a heat value of 9,000 to 12,000 Btu per pound. Some of this difference may be due to more intense folding of the Carbonado Formation (Gard, 1968, p. B12). More than 10 coal beds are present in the Spiketon Formation. These beds range from a few inches to as much as 11 feet in thickness.

Oligocene Series

Ohanapecosh Formation

Overlying the Spiketon Formation along the eastern margin of the Wilkeson-Carbonado coal field are well-indurated volcanic rocks thought to be in the lower part of the Ohanapecosh Formation. These rocks are mainly andesitic and dacitic in composition. The Ohanapecosh crops out in secs. 11, 14, and 23, T. 19 N., R. 6 E. It is best exposed in the steep valley walls of South Prairie Creek. These exposures consist of about 2,500 feet of sandstone, mudstone, conglomerate, and pyroclastic rocks. All strata are well indurated and of volcanic origin; they contain a few intercalated carbonaceous rocks, and several andesitic sills have intruded the volcanic sedimentary rocks.

The Ohanapecosh rocks, though locally black, brown, red, and white, are mostly grayish green. Volcanic sandstone, siltstone, and conglomerate in the Ohanapecosh are all similar in composition. Subangular fragments of andesitic and basaltic rock, and plagioclase feldspar are the main constituents (Gard, 1968, p. B16). The contact between Ohanapecosh rocks and the underlying Spiketon rocks on South Prairie Creek is obscured by talus, however, the rocks both above and below the contact are well exposed (Gard, 1968, p. B16-B17).

Quaternary System

Pleistocene Series

The western slopes of the Cascade Range and the Puget Sound lowland underwent extensive and repeated glaciation during the Pleistocene epoch. Willis (1898) described the glacial history and named two glacial stages, Admiralty and Vashon, and the Puyallup interglacial stage. Geologic mapping (Crandell, 1963, and Crandell and Gard, 1960) has revealed the presence of till, outwash, and glaciofluvial material deposited by both continental and alpine glaciers.

The deposits of Pleistocene age are chiefly drift consisting of sand and gravel and till (fig. 7). These deposits mantle the bedrock at most places in the Wilkeson-Carbonado coal field. The thickness of these surficial glacial deposits varies from a few feet to three or four hundred feet. Timber and air-chutes from the upper limits of mine workings to the surface reveal these depths of cover (Daniels, 1914, p. 15), however, the thickness of the glacial deposits has not been accurately determined through much of the area of the coal field.

FIGURE 7.--Glacial gravel and sand exposed east of Wilkeson Creek, SW$\frac{1}{4}$ sec. 27, T. 19 N., R. 6 E.

INTRUSIVE ROCKS

Intrusive igneous rocks in the Wilkeson-Carbonado coal field form dikes, sills, and small plugs in rocks of Eocene and Oligocene age. Fine-grained intrusive rocks consist of andesite and latite; medium-grained intrusive bodies are quartz diabase and hornblende dacite porphry. Although some of the sills appear to be fairly extensive, lack of adequate exposures prevents tracing them for more than a few hundred feet. Precise dating of the intrusive rocks is not possible. No evidence was found to suggest more than one time of intrusion (Gard, 1968, p. B18).

The largest intrusive body in the coal field crops out in the Carbon Gorge south of Carbonado. It is composed of quartz diabase and forms a sill at least 950 feet thick that can be traced along the gorge for nearly 3 miles and is intercalated between west-dipping beds of the Carbonado Formation. The sill is well exposed in sec. 16, south of Carbonado (fig. 8), where the Carbon Gorge crosses the sill diagonally from the base to top for a distance of three-fourths of a mile. The north end of the sill is not exposed, but the sill was penetrated in the Carbonado coal mines, where mine maps indicate that it tapers to a blunt, rounded end in the NE 1/4 sec. 9, T. 18 N., R. 6 E., about a mile southeast of Carbonado. The southward extension of the sill is covered by glacial drift, but a few scattered outcrops of quartz diabase suggest that the sill extends at least as far south as sec. 28, T. 18 N., R. 6 E. (Gard, 1968, p. B18).

Contacts between the sill and the enclosing Carbonado Formation are sharp and mostly conformable with the bedding of the sedimentary rocks. The lower contact is exposed on State Highway 165 about 400 yards south of Fairfax Bridge, where less than an inch of the underlying carbonaceous shale has been baked and hardened (Gard, 1968, p. B19). The upper contact of the sill is exposed in a gully just northwest of Fairfax Bridge where the sill appears to be conformable with an overlying siltstone that was only slightly affected by the heat of the intrusion.

FIGURE 8.--Quartz diabase intrusion in Carbonado Formation, State Highway 165, 2 miles south of Carbonado, sec. 16, T. 18 N., R. 6 E.

Sills and dikes of pyroxene andesite have intruded all the Eocene and Oligocene formations in the vicinity of the Wilkeson-Carbonado coal field. Sills are more common than dikes in the Carbonado and Spiketon Formations because the bedding planes offered lines of least resistance to the invading magma. With few exceptions these dikes and sills are dark-gray, black, or greenish-gray rocks that vary in texture from fine- to medium-grained porphyry and have prominent feldspar and pyroxene phenocrysts (Gard, 1968, p. B21).

STRUCTURE

General Features

The coal-bearing strata of the Wilkeson-Carbonado coal field have been intensely folded and faulted (fig. 9). The predominant structural feature is a broad northward-trending asymmetrical anticline which is known regionally as the Carbon River anticline (Gard, 1968, p. B4). The Carbonado Formation is exposed along the axis of the anticline; the Northcraft, Spiketon, and Ohanapecosh Formations crop out on the east limb; but only the Northcraft is exposed on the west limb. The Carbon River anticline can be traced from Burnett southward for more than 30 miles to the Nisqually River. North of Burnett the anticline is concealed by glacial deposits. Along the core of the anticline are several smaller tightly folded anticlines and synclines whose trends parallel that of the major structure. All the folds have been broken by high-angle (chiefly reverse) faults which trend subparallel to the fold axes. Dips in the core of the anticline range from 0° to 90°.

The Carbon River anticline is believed to have resulted from east-west lateral compression acting on Carbonado rocks between a butress of thick downwarped Ohanapecosh Formation to the east and the competent Northcraft Fromation to the west (fig. 10).

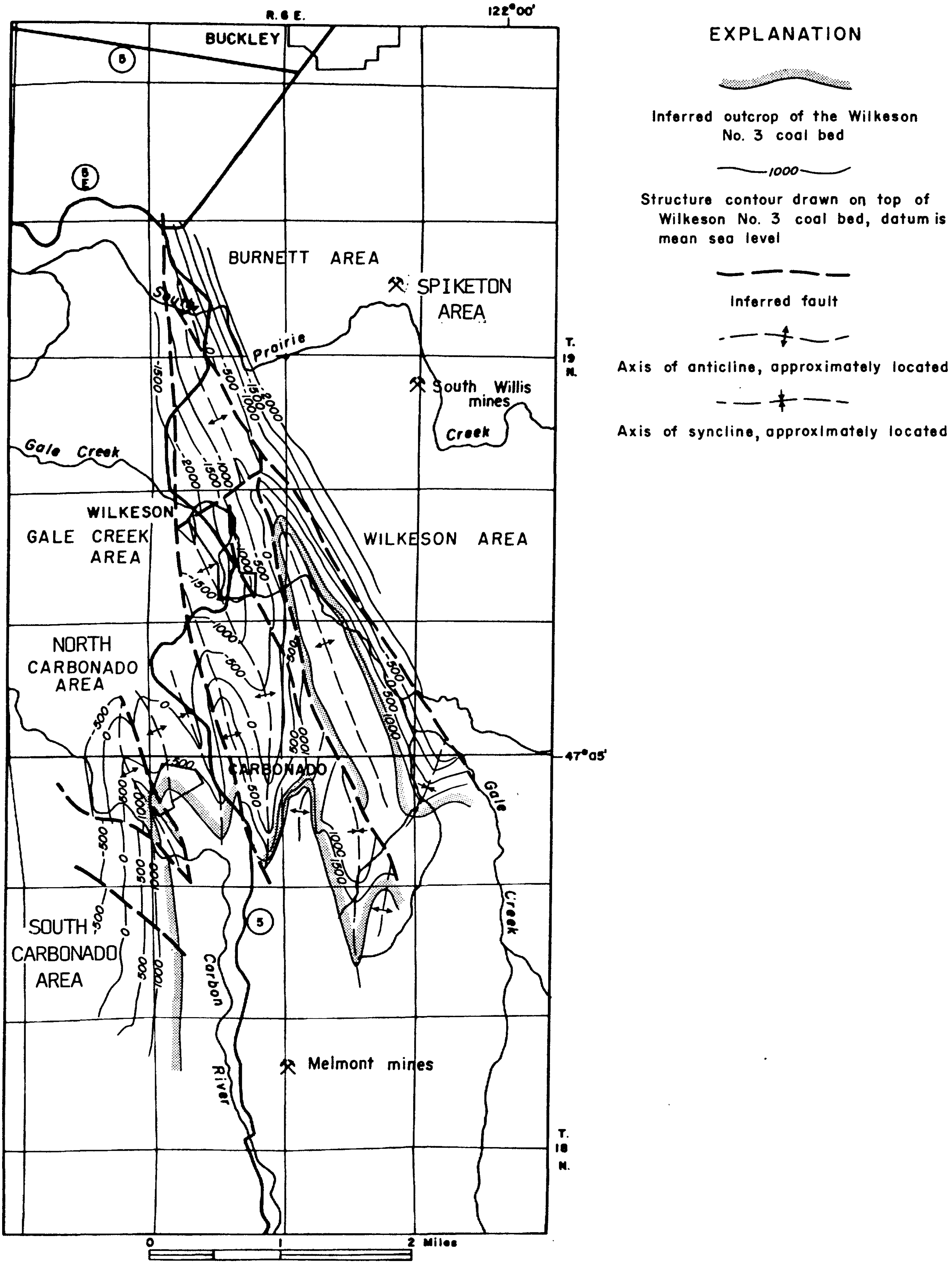

FIGURE 9.—GENERALIZED STRUCTURE CONTOUR MAP OF THE WILKESON-CARBONADO COAL FIELD
(From Beikman and others, 1961, p. 64)

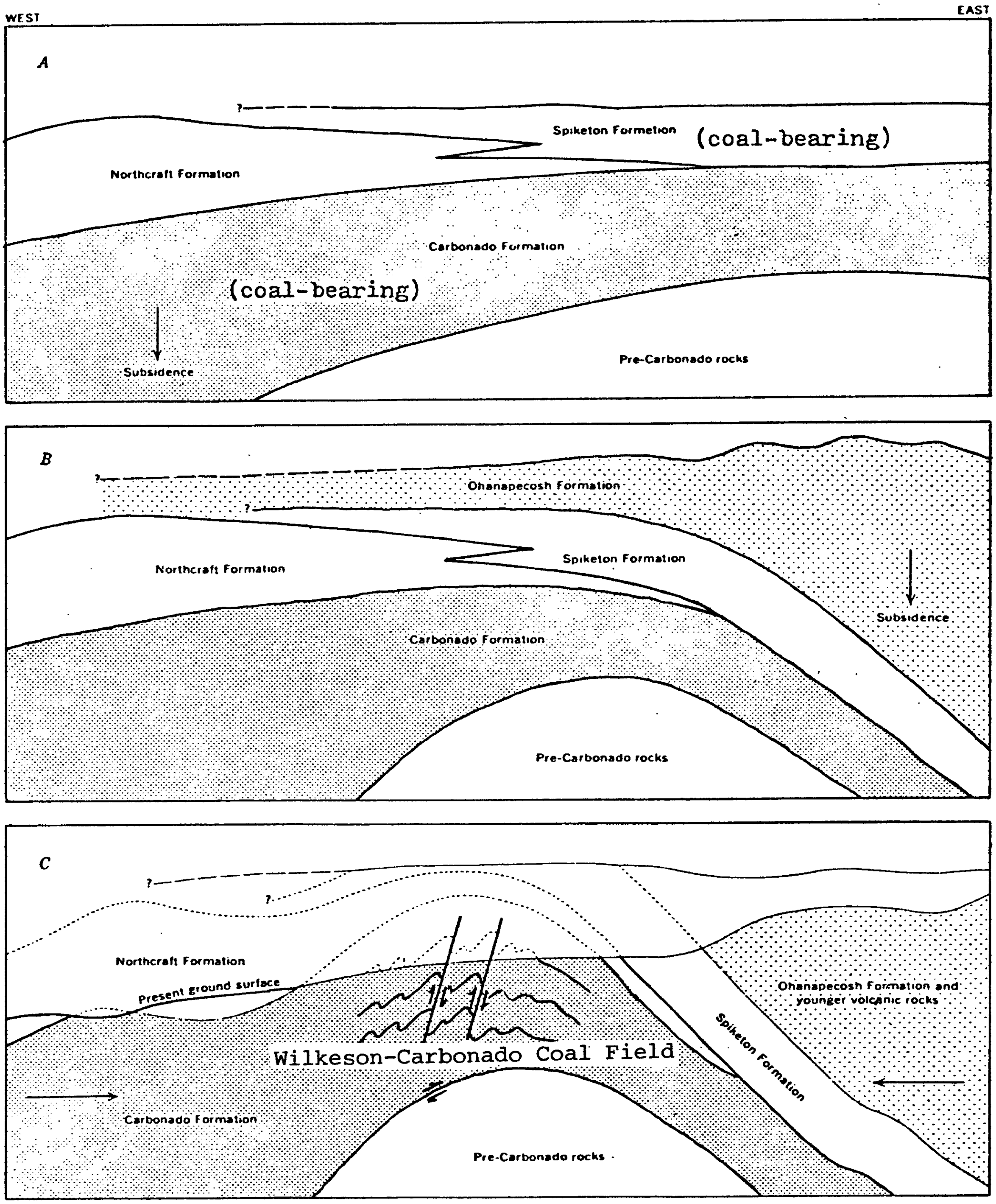

FIGURE 10.--Hypothetical sequence of structural development in the Carbon River (Wilkeson) anticline. A, late Eocene time; B, Oligocene time; C, late Oligocene to Miocene time. (modified from Gard, 1968, p. B28)

Because of the widespread distribution of Quaternary deposits and the cover of dense vegetation, outcrops are sparse and small, and marker horizons generally cannot be recognized or traced. For these reasons, fold axes and fault traces shown on the geologic map (pl. 1) are only approximately located. Details of the geologic structure are inferred chiefly from subsurface information obtained from coal mines in the Carbonado and Spiketon Formations. Most of the structure shown on plate 1 was interpreted from published and unpublished coal-mine maps (Daniels, 1914; Bird and Marshall, 1931; Beikman and others, 1961; Gard, 1968).

Folds

The Carbonado Formation has been deformed into a series of small, tight synclines and anticlines (pl. 1, fig. 9), mostly in the core of the Carbon River anticline. The largest of these is the Wilkeson anticline, Which trends N. 30° W. and plunges at a low angle northward. Average dips on the flanks of the anticline are generally about 60°. Although overturned beds are rare, nearly vertical dips are common. The Wilkeson anticline has been delineated by attitudes of beds exposed in coal mines from Burnett southward for a distance of about 5 miles (Gard, 1968, B26).

A small tightly folded syncline (fig. 11) and anticline lie on the east flank of the Wilkeson anticline in sec. 2, T. 18 N., R. 6 E. The folds which trend northeastward and plunge in the same direction, are displaced along the Burnett fault in sec. 35, T. 19 N., R. 6 E. Their northward extensions are exposed in the valley walls of South Prairie Creek just east of the map area (pl. 1) in secs. 23, 24, 25, T. 19 N., R. 6 E. Gard (1968, p. B26) noted that the syncline continues 6 miles to the northeast into sec. 6, T. 19 N., R. 7 E. North and south of these folds, the strata in the eastern part of the coal field resume their fairly uniform northwest-southeast strike with slightly steeper dips to the east.

Two anticlines and an intervening syncline occur west of the Wilkeson anticline east of Carbonado in secs. 3 and 10, T. 18 N., R. 6 E. (pl. 1). The folded rocks do not crop out, but the folds were identified during exploration for coal.

FIGURE 11.--Syncline in Carbonado Formation, west fork of Gale Creek, sec, 2, T. 18 N., R. 6 E. Upper photograph, view northward; lower photograph, view eastward.

Maps of the mine workings at Melmont reveal complexities of structure in secs. 9, 10, 15, and 16, T. 18 N., R. 6 E., that were unsuspected prior to mining (Gard, 1968, p. B26). In the NE cor. sec. 21, T. 18 N., R. 6 E., the Melmont tunnel (originally known as the Blossberg tunnel) was driven 1,600 feet eastward from the tracks of the now abandoned Northern Pacific Railroad on the east side of the Carbon River. The tunnel, driven normal to the strike of the beds, intersected a high-angle reverse fault about 275 feet from the portal and then crossed steeply dipping beds that exhibit small tightly folded and faulted anticlines and synclines.

Maps of mine workings north of the Carbon River near Fairfax show similar small north-plunging folds in the Carbonado Formation. Mine workings in sec. 34, T. 18 N., R. 6 E., south of Fairfax revealed a series of small south-plunging folds that continue southward at least as far as the Montezuma mine, which is on Evans Creek about a mile south of the map (pl. 1) boundary (Gard, 1968).

North of the Willis fault, in the vicinity of Carbonado, in secs. 32 and 33, T. 19 N., R. 6 E. and in secs. 32 and 33, T. 19 N., R. 6 E., the coal-bearing strata are tightly folded and faulted. Three anticlines and three synclines comprise this tightly folded belt. The folds plunge northward and are not accurately defined north of the centers of secs. 32 and 33. In marked contrast, the strata south of the Willis fault at Carbonado maintain a fairly uniform strike southward. In secs. 16 and 17, T. 18 N., R. 6 E., however, the strata are folded into a small northwest-trending syncline and anticline.

A minor anticline and syncline occur on the west limb of the Wilkeson anticline near Wilkeson. These folds appear to die out northward and at Burnett, near the northern margin of coal field, the strata on the faulted west limb of the Wilkeson anticline maintain a fairly regular westerly dip.

Faults

The strata in the Wilkeson-Carbonado coal field are cut by many high-angle faults which generally are not seen at the surface and were discovered during coal mining. There appears to be two distinct sets of faults. One set consisting of strike faults and includes both high-angle reverse and normal faults (such as the Burnett, Wilkeson, Menzies, and Deveraux faults) that trend subparallel to the fold axes. The other set consists of normal faults (such as the Willis and Miller faults) that transect and postdate the strike faults. The strike faults trend north-northwestward, have relatively large displacements, and are commonly upthrown on their west sides. These faults occur at or near the axes of minor folds and probably formed during the late stages of folding (Gard, 1968, p. B26).

The Burnett fault was described by Daniels (1914, p. 43) as a hinge fault. At the north end near Burnett, the west side of this fault is downthrown as much as 1,000 feet, whereas at the south end the same side is upthrown an unknown amount. At section B-B' (pl. 1), the east side is downthrown about 900 feet, as calculated from the position of the Northcraft Formation and from the stratigraphic separation between the base of this formation and the Wingate coal bed (Gard, 1968, p. B26).

Most normal cross faults trend east-southeast, east, or northeast, cut folds and strike faults, and offset coal beds. The cross fault with the largest known displacement is the Willis fault, which offsets the coal beds mined at Carbonado. The south side of the fault moved downward possibly as much as 1,800 feet (Gard, 1968, p. B26) displacing west-dipping coal seams eastward on the south side of the fault. The Miller fault lies 2,000 feet southwest of the Willis fault, is parallel to it, and also has the south side downthrown. Maps of the coal mines under Wingate Hill suggest that other cross faults may lie farther south, but because of lack of specific information, cross faults are not shown on the geologic map south of Wingate Hill.

COAL

Wilkeson-Carbonado Coal Field

Discovery and development

Bituminous coal was discovered about 1862 in outcrops of the Carbonado Formation in the Carbon River Gorge, and mining began in 1874. Coal from the Wilkeson-Carbonado coal field, particularly that from the Carbonado Formation, proved to be the most satisfactory coking coal on the west coast, and large quantities of coke were produced. The coal ranges in rank from high-volatile A bituminous to low-volatile bituminous and occurs in the more than 8,000 feet of sedimentary rocks comprising the Carbonado and Spiketon Formations within the Puget Group. Willis (1886) reported "127 carbonaceous beds in the Wilkeson section, of which 17 are workable coal veins 3 to 15 feet thick". The coal beds vary in thickness, extent, and character throughout the coal field, and in the past, about 40 beds have been mined or opened in several isolated areas within the field.

Knowledge of the coal deposits is confined largely to areas of extensive mining, and very little is known about intervening areas or about the relation of one area to another. For this reason, the detailed descriptions of the coal deposits in this report are given by separated geographic areas within the Wilkeson-Carbonado coal field, which are: the Wilkeson-Carbonado area, including the Burnett, Gale Creek, Wilkeson, and Carbonado mines; the Melmont area; the Fairfax-Montezuma area, including the mines at Fairfax and Montezuma; and, the Spiketon area, including the Spiketon and South Willis mines.

Wilkeson-Carbonado area

<u>Location and coal-bearing sequence</u>

The Wilkeson-Carbonado area includes the Burnett, Gale Creek, Wilkeson, North Carbonado, and South Carbonado mines (pl. 1). Nine coal beds of economic importance, which were mined fairly extensively in the above mines, occur in the lower 3,000 feet of the Carbonado Formation; the upper 2,000 feet of the formation is virtually barren of coal. Several additional coal beds are present in the Wilkeson-Carbonado area but at most places they are not of minable thickness. Although a coal bed may have been mined in several of the mines within the area, the bed is known by a different name or number in each of the mines. For example, the uppermost coal of economic importance in the Carbonado Formation, the No. 1 coal bed at Burnett, is known as the Peanut No. 2 in the Gale

Creek mines, the Wilkeson No. 5 in the Wilkeson mines, the Miller or No. 3 coal bed in the Carbonado mines north of the Carbon River, and as the Miller or No. 2 coal bed in the Carbonado mines south of the Carbon River. These and other coal bed correlations used in this report for the Wilkeson-Carbonado area are shown on figure 12.

Columnar sections of the coal-bearing sequence at the Burnett, Gale Creek, and Wilkeson mines are shown in figure 13. The coal-bearing sequence at the Carbonado mines north of the Carbon River is shown in figure 14, and the sequence in the Carbonado mines south of the river is shown in figure 15. Most of the coal produced in the Wilkeson-Carbonado area came from the Wilkeson Nos. 2, 3, 4, and 5 coal beds and the correlatives of these beds in the Carbonado, Burnett, and Gale Creek mines; and, from the No. 5 coal bed in the Carbonado mines. Other coal beds that have been mined extensively are the Wilkeson Nos. 1 and 7, and their correlatives in the Carbonado mines; and, the Morgan and Big Ben coal beds in the Carbonado mines north of the Carbon River (Livingston, 1974, p. 51).

Measured sections of the coal beds in the Carbonado Formation mined at Burnett are shown in figure 16; sections of the coal beds mined in the Gale Creek and Wilkeson mines are shown in figures 17 and 18; sections of the coal beds mined in the Carbonado mines are shown in figure 19. As noted in these sections, thin to thick shale and clay partings are common in most of the coal beds in the Carbonado Formation and contribute to the high ash content of the coal beds in the Wilkeson-Carbonado coal field.

The coal beds for which reserves were estimated range from 2 to 8 feet in thickness (Beikman and others, 1961, p. 66). Most of the coal beds vary somewhat in thickness and in the number and thickness of partings included in the bed. The partings generally consist of clay, shale, or bone. Information is lacking on roof and floor conditions but available data indicates that thin, friable, carbonaceous shale commonly overlie many of the coal beds, and that many of the coal beds grade to bony coal and carbonaceous shale at the base of the bed.

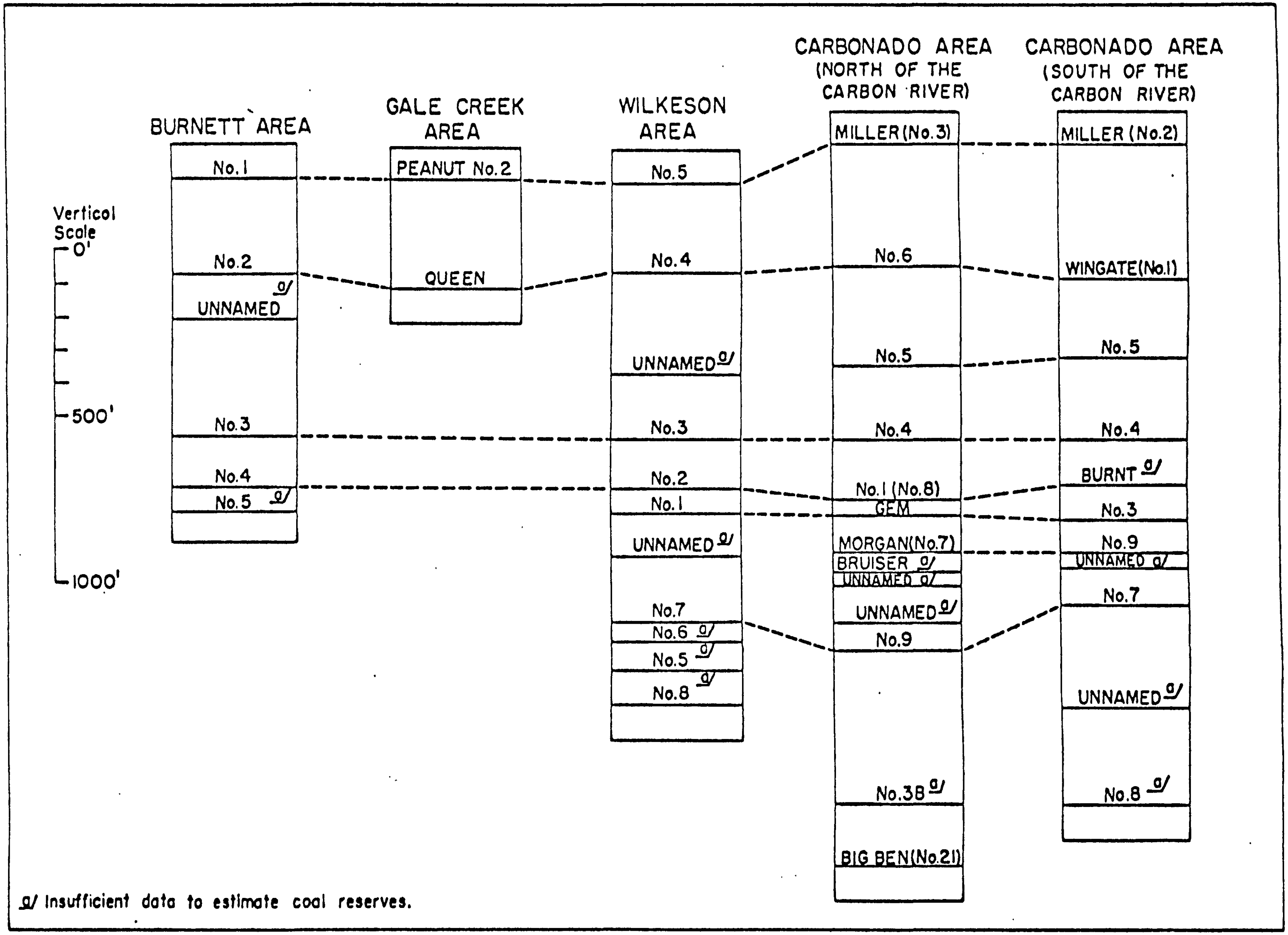

Figure 12.—Generalized columnar sections in the Wilkeson-Carbonado coal field showing coal beds and correlations used in estimating coal reserves (From Beikman and others, 1961, p. 65)

page 37 follows

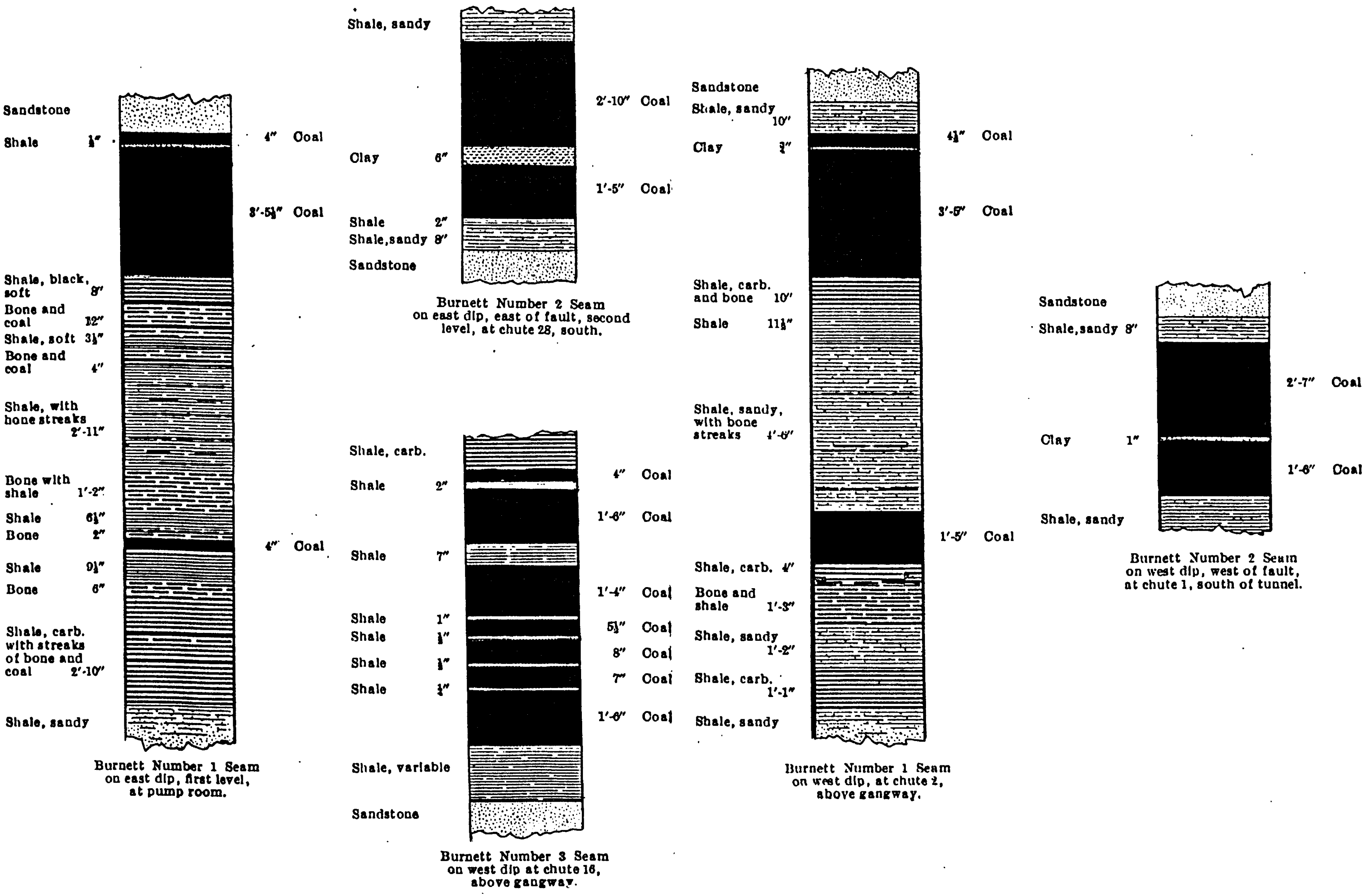

FIGURE 16.-- Sections of coal in the Carbonado Fromation at Burnett
(from Daniels, 1914, p. 61, 63)

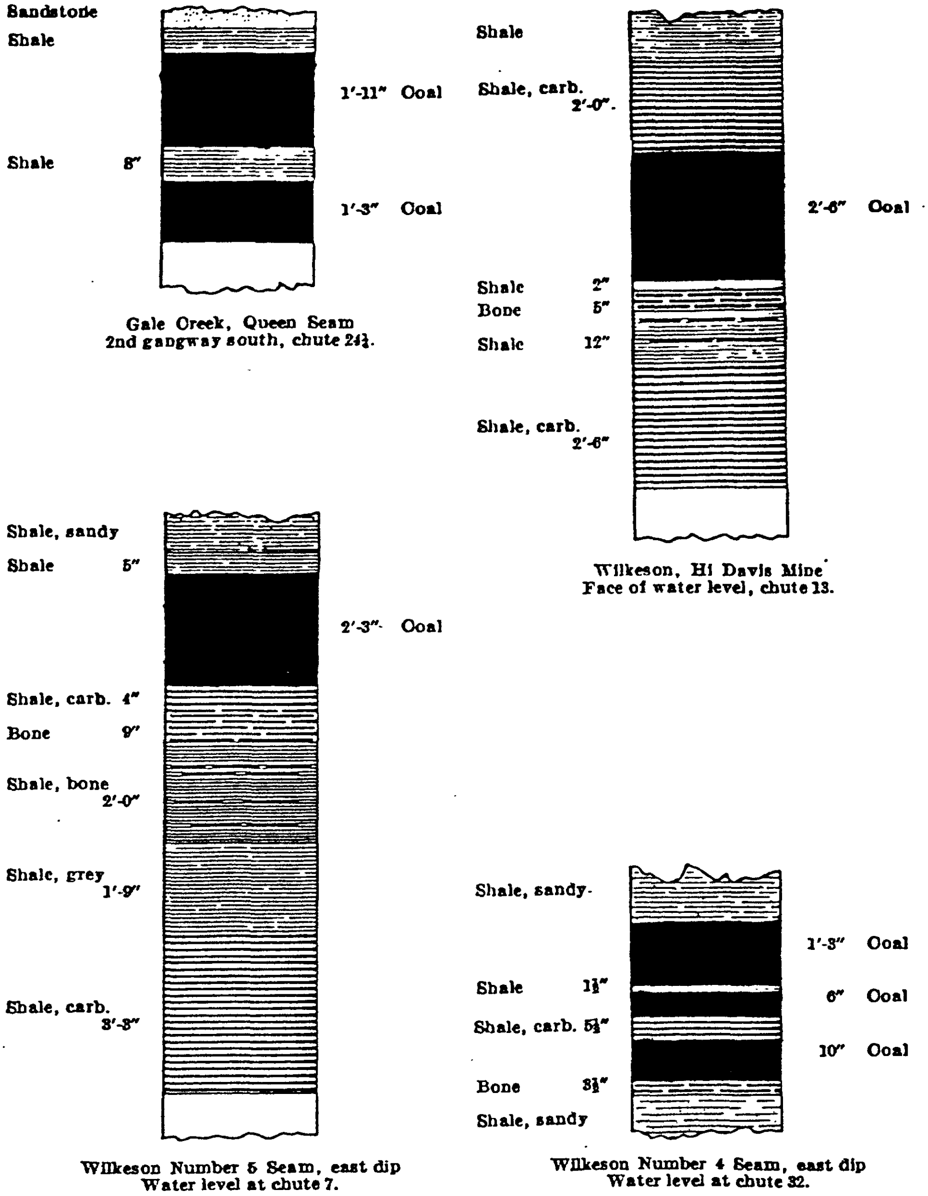

FIGURE 17.--Sections of coal in the Carbonado Formation at Gale Creek and Wilkeson (from Daniels, 1914, p. 64)

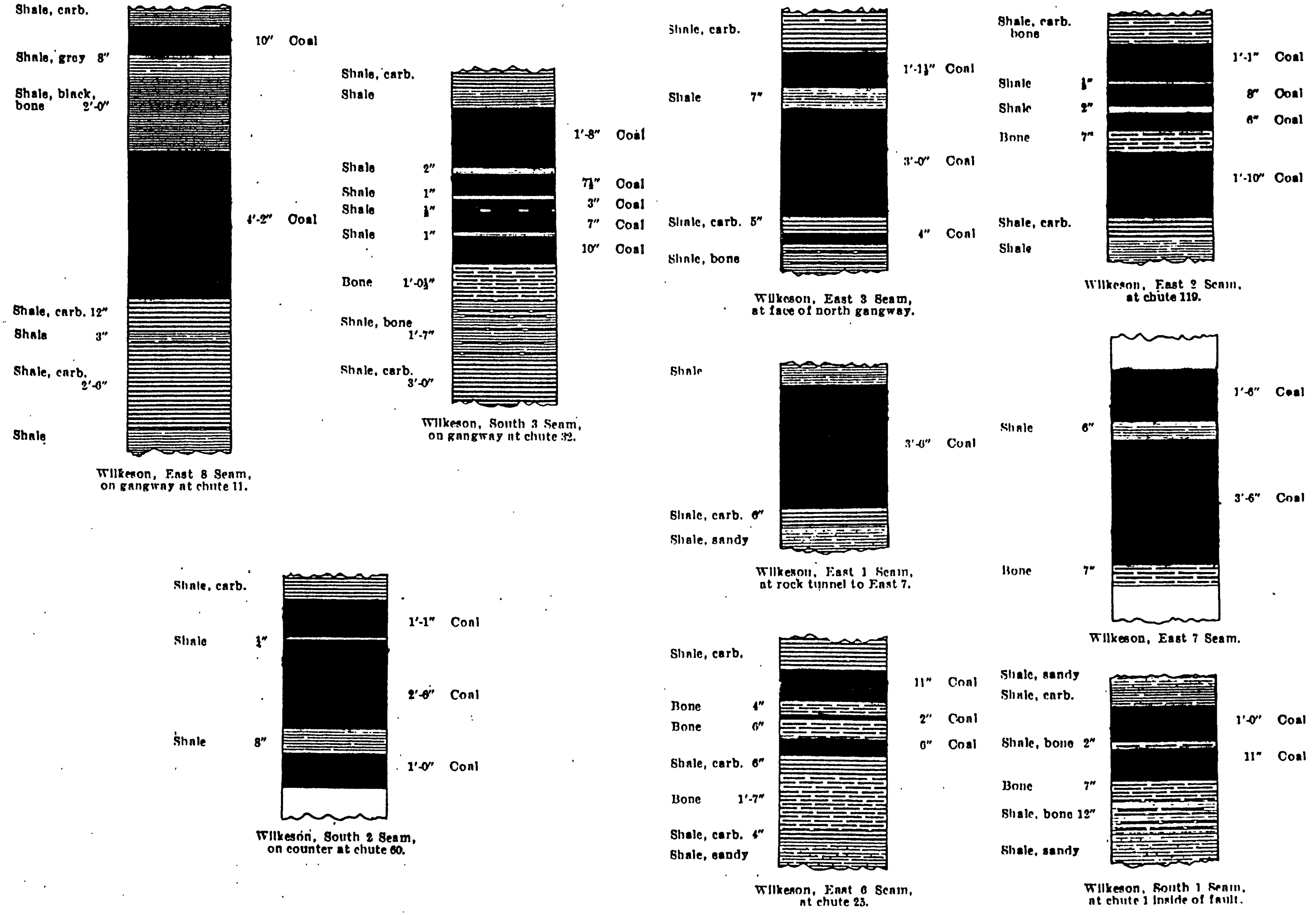

FIGURE 18.--Sections of coal in the Carbonado Formation at Wilkeson

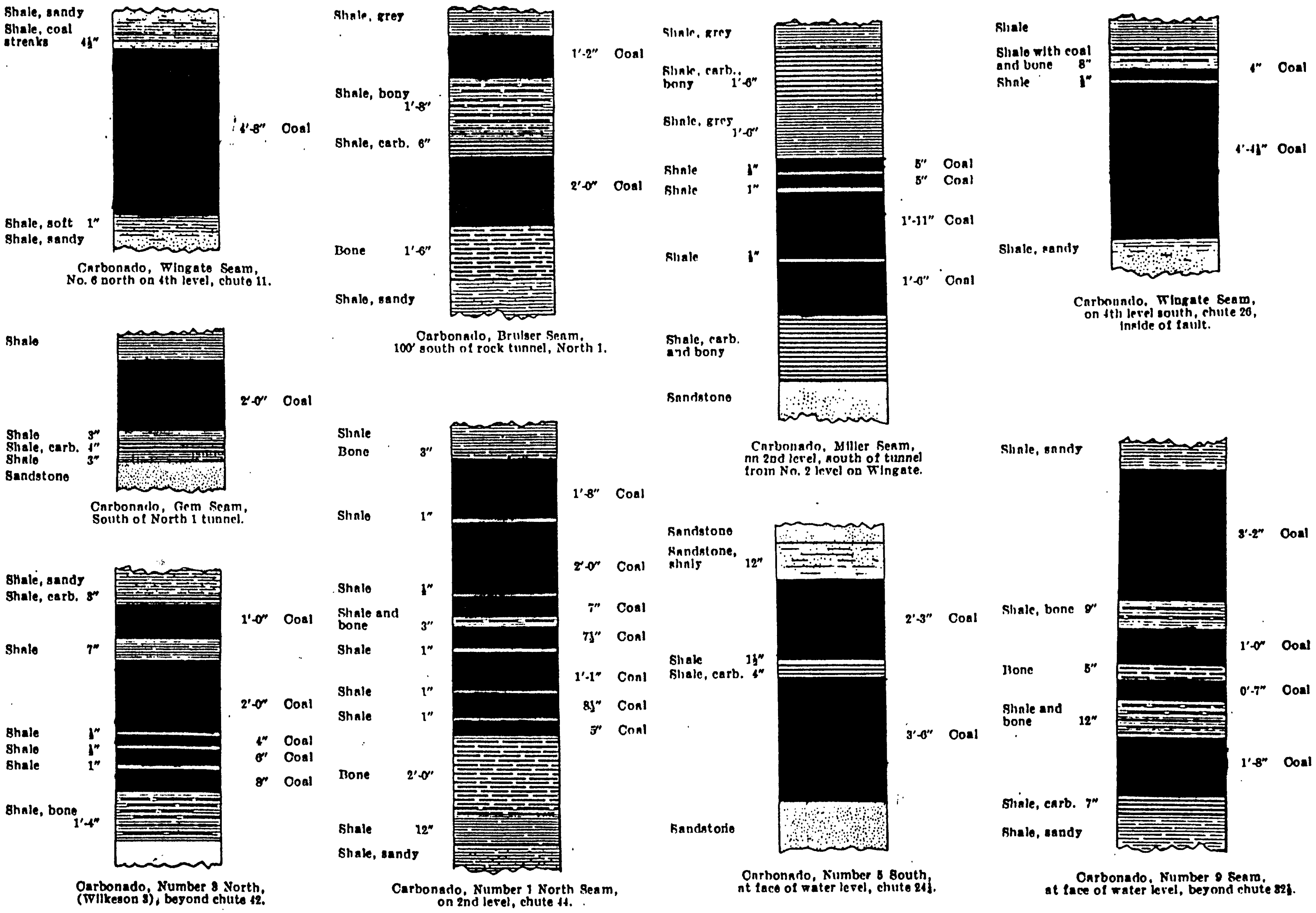

FIGURE 19.--Sections of coal in the Carbonado Formation at Carbonado
(from Daniels, 1914, p. 71-72)

Structural attitude of coal beds

The coal beds are steeply dipping throughout most of the Wilkeson-Carbonado area, with an average dip of about 60°. Although overturned beds are rare, near vertical dips are common. The Wilkeson anticline is the principal structure in the Burnett mines. The east limb of the anticline is cut by the Burnett fault, a hinge fault along which the strata on the east side are upthrown more than 1,000 feet. The west limb of the anticline is cut by a westward dipping high-angle reverse fault, and the west side of the fault is upthrown about 500 feet (see section A-A', pl. 1).

The Gale Creek mine is on the west flank of the Wilkeson anticline where the dip of the coal beds ranges from 25° to 60° W. The beds are cut by the Wilkeson fault in the southern part of the workings. Both limbs of the Wilkeson anticline were mined in the Wilkeson mines. On the east limb of the anticline the dip of the strata varies between 20° and 60° E., and averages about 60° E. On the west limb of the anticline the strata are more steeply inclined and dips of 85° W are not uncommon.

Dips ranging from 25° to 85° are encountered in the North Carbonado mine workings where the strata are tightly folded and faulted. Three anticlines and three synclines comprise this tightly folded belt which is cut by two high-angle faults (see C-C', pl. 1). South of the Carbon River on the downthrown side of the Willis fault, the strata in the South Carbonado mines maintain a fairly uniform strike southward and a westerly dip that seldom exceeds 50°. The coal beds are offset by the Miller fault which lies about 2,000 feet southwest of the Willis fault.

Physical and chemical properties

Coal in the Wilkeson-Carbonado area ranges in rank from high-volatile A bituminous to medium-volatile bituminous, and much of the coal has good coking qualities. The ash content of the coal has a range of 6.0 to 25.7 percent and averages about 12 percent. The moisture content ranges from 1.1 to 7.4 percent and averages about 3 percent. The sulfur content ranges from 0.3 to 3.2 percent and averages 0.7 percent (Beikman and others, 1961, p. 66). The average chemical analyses of the various coal beds mined in the Wilkeson-Carbonado area are given in table 2. Analyses of mine, tipple, and delivered samples of coal from the Wilkeson-Carbonado coal field are given in tables 3, 4, and 5. True specific gravities of several coals in the Wilkeson-Carbonado field are given in table 6.

Table 2.—Averages of analyses (as-received basis) of coal samples from the Wilkeson-Carbonado coal field, Pierce County, Washington

(Coal bed names used are those at Wilkeson and at Carbonado north of the Carbon River. M—moisture; VM—volatile matter; FC—fixed carbon; Btu—British thermal units. Sources of analyses are Fieldner and others, 1931; Cooper and Abernethy, 1941; and Daniels and others, 1958.)

Coal bed	Proximate (percent)				Sulfur (percent)	Btu	Number of analyses used in obtaining average
	M	VM	FC	Ash			
Wilkeson No. 5 --	3.9	33.3	54.5	8.4	0.8	13,475	6
Wilkeson No. 4 --	3.3	34.2	52.1	10.3	1.1	13,468	26
Carbonado No. 5 -	3.8	34.9	50.6	10.6	.6	12,910	4
Wilkeson No. 3 --	2.8	31.4	51.4	14.2	.4	12,637	18
Wilkeson No. 2 --	3.7	28.8	52.4	14.9	.6	12,302	16
Wilkeson No. 1 --	2.7	28.7	52.7	15.7	1.1	12,483	6
Morgan (No. 7) --	2.6	29.9	48.7	18.7	.5	12,398	6
Wilkeson No. 7 --	2.8	24.3	61.9	10.8	.5	13,410	5
Big Ben ---------	3.7	29.9	53.3	13.0	.5	12,843	3

(From Beikman and others, 1961, p. 66)

TABLE 3.—Analyses of mine samples from Pierce County, Washington coals (from Fieldner and others, 1931)

				Sample			Proximate				Ultimate						Calorific value		
Location, county, and town	Mine	Bed	Location in mine	Kind [1]	Condition [2]	Laboratory No. [3]	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Air-dry loss	Calories	British thermal units	Softening temperature °F. [4]
PIERCE COUNTY																			
Ashford	Prospect	Nisqually Chief	100 feet from entry mouth	B	1	12581	5.8	15.3	64.7	24.2	.4	------	------	------	------	3.6	5,783	10,410	2,680
					2			16.2	58.1	25.7	.4	------	------	------	------		6,139	11,050	
Do	Masbel	Unnamed	End of gangway, lower bench.	B	1	9884	4.1	24.4	44.7	26.8	.4	4.3	58.2	1.4	8.9	2.6	5,717	10,290	2,850
					2			25.4	46.7	27.9	.5	4.0	60.7	1.5	5.4	------	5,967	10,740	
					3			35.3	64.7	------	.6	5.6	84.2	2.0	7.6	------	8,272	14,890	
Do	do	do	End of gangway, upper bench.	B	1	9885	4.0	22.0	36.0	38.0	.7	3.7	47.0	1.3	9.3	2.4	4,672	8,410	2,710
					2			22.9	37.5	39.6	.7	3.4	48.9	1.3	6.1	------	4,867	8,760	
					3			38.0	62.0	------	1.2	5.6	81.0	2.2	10.0	------	8,061	14,510	
7 miles east of	Longmire	do	Face, open prospect	B	1	6486	9.4	12.8	51.3	26.5	.4	------	------	------	------	7.0	5,250	9,450	------
					2			14.1	56.6	29.3	.4	------	------	------	------		5,800	10,440	
Buckley, 2 miles south of.	Black Carbon	Peacock	Face, prospect	A	1	A56769	4.7	32.3	42.1	20.9	.6	5.4	59.0	1.6	12.5	2.9	6,006	10,810	2,820
					2			33.9	44.2	21.9	.6	5.1	61.8	1.7	8.9	------	6,300	11,340	
					3			43.4	56.6	------	.8	6.5	79.2	2.2	11.3	------	8,067	14,520	
Do	do	No. 10	Face of prospect	A	1	A56770	4.5	33.4	43.9	18.2	.4	5.4	61.6	1.7	12.7	2.4	6,194	11,150	2,900
					2			34.9	46.1	19.0	.4	5.2	64.5	1.8	9.1	------	6,489	11,680	
					3			43.1	56.9	------	.5	6.4	79.6	2.2	11.3	------	8,011	14,420	
Burnett	Burnett	No. 3	North end of gangway, on rock tunnel, lower bench.	B	1	9888	4.7	35.2	46.9	13.2	.4	5.4	67.6	1.9	11.5	2.7	6,817	12,270	------
					2			37.0	49.2	13.8	.4	5.1	70.9	2.0	7.8	------	7,150	12,870	
					3			42.9	57.1	------	.5	5.9	82.3	2.3	9.0	------	8,300	14,940	
Do	do	do	North end of gangway, on rock tunnel, upper bench.	B	1	9889	3.6	36.8	45.5	14.1	.4	5.4	67.8	1.8	10.5	1.8	6,872	12,370	2,350
					2			38.2	47.2	14.6	.4	5.2	70.3	1.8	7.7	------	7,128	12,830	
					3			44.8	55.2	------	.5	6.0	82.3	2.1	9.1	------	8,350	15,030	
Do	do	do	Manway south of rock tunnel.	B	1	9800	3.2	35.0	49.3	12.5	.4	5.3	70.7	2.0	9.1	1.3	7,067	12,720	2,420
					2			36.2	50.9	12.9	.4	5.1	73.1	2.0	6.5	------	7,300	13,140	
					3			41.5	58.5	------	.5	5.8	83.9	2.3	7.5	------	8,378	15,080	
Do	do	do	3 north level, counter, 28 chute.	A	1	90597	3.1	38.3	47.4	11.2	.6	------	------	------	------	1.5	7,106	12,790	2,480
					2			39.5	48.9	11.6	.6	------	------	------	------	------	7,343	13,200	
Do	do	do	3 north level, below 3 crosscut, 21 chute.	A	1	90598	3.0	37.4	44.4	15.2	.4	------	------	------	------	1.5	6,700	12,060	2,450
					2			38.5	45.9	15.6	.4	------	------	------	------	------	6,906	12,430	
Do	do	No. 2	1 crosscut, south of rock tunnel,	B	1	9891	3.7	36.0	52.2	8.1	.8	5.6	73.9	2.0	9.6	2.4	7,539	13,570	2,320
					2			37.4	54.2	8.4	.8	5.4	76.7	2.1	6.6	------	7,828	14,090	
					3			40.9	59.1	------	.9	5.8	83.8	2.3	7.2	------	8,550	15,390	
Do	do	do	3 south level, east dip, 37 chute.	A	1	90604	7.4	36.4	48.2	8.0	1.2	------	------	------	------	6.4	7,228	13,010	2,220
					2			39.3	52.1	8.6	1.3	------	------	------	------	------	7,800	14,040	
Do	do	do	3 south level, east dip, 17 chute.	A	1	90605	4.2	39.4	45.8	10.6	2.1	------	------	------	------	3.3	7,233	13,020	2,150
					2			41.1	47.8	11.1	2.2	------	------	------	------	------	7,550	13,590	
Do	do	No. 2½	3 north level, rope incline	A	1	90601	3.5	36.7	49.9	9.9	1.9	------	------	------	------	2.5	7,294	13,130	2,280
					2			38.0	51.7	10.3	2.0	------	------	------	------		7,556	13,600	
Do	do	do	3 north level, bony coal	A	1	90602	4.9	26.0	26.7	42.4	1.8	------	------	------	------	3.6	4,100	7,380	2,590
					2			27.3	28.1	44.6	1.9	------	------	------	------		4,311	7,760	
Do	do	do	3 south level, 8 south crosscut, 10 chute.	A	1	90603	4.1	37.9	48.8	9.2	1.9	------	------	------	------	3.1	7,333	13,200	2,260
					2			39.6	50.8	9.6	2.0	------	------	------	------	------	7,650	13,770	
Do	do	No. 4	3 north level, 54 chute	A	1	90599	6.2	33.6	45.7	14.5	.4	------	------	------	------	4.5	6,517	11,730	2,750
					2			35.8	48.7	15.5	.4	------	------	------	------	------	6,944	12,500	
Do	do	do	3 north level, 41 pillar, 5 crosscut.	A	1	90600	4.5	34.2	48.1	13.2	.7	------	------	------	------	3.0	6,750	12,150	2,390
					2			35.9	50.3	13.8	.8	------	------	------	------	------	7,067	12,720	
Carbonado	Carbon Hill	No. 1	West side of syncline, 11 chute.	B	1	2460	4.1	31.2	50.1	14.6	.4	------	------	------	------	2.4	------	------	------
Do	do	do	End of rock tunnel	B	1	9569	2.8	28.1	50.8	18.3	3.2	4.9	65.6	1.9	6.1	2.2	6,689	12,040	2,210
					2			28.9	52.2	18.9	3.3	4.6	67.5	1.9	3.8	------	6,883	12,390	
					3			35.6	64.4	------	4.1	5.7	83.2	2.4	4.6	------	8,478	15,260	
Do	do	do	1 level, 100 feet up 13 chute	B	1	9572	3.4	32.2	49.5	14.9	.5	5.3	67.2	2.0	10.1	1.8	6,806	12,250	2,720
					2			33.3	51.3	15.4	.5	5.1	69.6	2.1	7.3	------	7,044	12,680	
					3			39.4	60.6	------	.6	6.1	82.3	2.5	8.5	------	8,322	14,980	
Do	do	Wingate	Near small fault on level below river.	B	1	2459	3.5	39.9	50.3	6.3	.9	------	------	------	------	1.4	------	------	------
Do	do	do	1 crosscut above 3 level	B	1	9558	4.0	36.9	52.7	6.4	.5	5.8	74.0	2.2	11.1	2.0	7,378	13,280	2,260
					2			38.4	54.9	6.7	.5	5.6	77.1	2.3	7.8	------	7,689	13,840	
					3			41.1	58.9	------	.6	6.0	82.6	2.4	8.4	------	8,239	14,830	
Do	do	do	North and south ends of 3 level gangway.	B	1	9560	2.7	36.3	52.9	8.1	.5	5.8	74.1	2.1	9.4	1.5	7,522	13,540	2,180
					2			37.3	54.3	8.4	.5	5.6	76.2	2.2	7.1	------	7,733	13,920	
					3			40.7	59.3	------	.6	6.2	83.1	2.4	7.7	------	8,439	15,190	
Do	do	do	10 crosscut, 2 level, between 56 and 57 chutes.	B	1	9601	2.9	32.8	53.6	10.7	1.1	5.4	70.9	1.8	10.1	1.1	7,144	12,860	2,190
					2			33.8	55.2	11.0	1.1	5.2	73.0	1.9	7.8	------	7,350	13,230	
					3			38.0	62.0	------	1.3	5.9	82.0	2.1	8.7	------	8,256	14,860	
Do	do	No. 2	End of right gangway	B	1	9557	3.8	27.1	53.7	15.4	.4	5.0	68.2	2.0	9.0	2.8	6,850	12,330	2,640
					2			28.1	55.9	16.0	.4	4.7	70.9	2.1	5.9	------	7,128	12,830	
					3			33.5	66.5	------	.5	5.6	84.4	2.5	7.0	------	8,478	15,260	
Do	do	No. 3	3 north main entry	A	1	552-D	2.9	30.9	50.2	16.0	.5	------	------	------	------	1.8	6,906	12,430	------
					2			31.9	51.6	16.5	.5	------	------	------	------		7,117	12,810	
Do	do	do	South end of gangway, lower bench.	B	1	9555	3.8	26.6	49.3	20.3	.4	5.0	63.9	1.9	8.5	3.0	6,400	11,520	2,840
					2			27.7	51.2	21.1	.4	4.8	66.4	2.0	5.3	------	6,650	11,970	
					3			35.0	65.0	------	.5	6.0	84.1	2.6	6.8	------	8,428	15,170	
Do	do	do	South end of gangway, upper bench.	B	1	9565	4.2	30.0	52.4	13.4	.3	5.1	70.1	1.9	9.2	3.5	7,033	12,660	2,640
					2			31.3	54.7	14.0	.3	4.8	73.2	2.0	5.7	------	7,339	13,210	
					3			36.4	63.6	------	.4	6.6	85.1	2.3	6.6	------	8,539	15,370	
Do	do	No. 4	200 feet up 14 chute	B	1	9562	3.2	34.8	51.6	10.4	.3	5.5	72.5	1.9	9.4	2.0	7,339	13,210	2,350
					2			36.0	53.2	10.8	.3	5.3	74.9	2.0	6.7	------	7,553	13,650	
					3			40.3	59.7	------	.4	5.9	84.0	2.2	7.5	------	8,500	15,300	
Do	do	No. 5	End of gangway on water level.	B	1	9564	3.6	29.7	50.3	16.4	.6	4.9	65.5	2.1	10.5	1.9	6,506	11,710	2,890
					2			30.8	52.2	17.0	.6	4.7	68.0	2.2	7.5	------	6,750	12,150	
					3			37.2	62.8	------	.7	5.7	81.8	2.6	9.2	------	8,128	14,630	
Do	do	No. 9	do	B	1	9556	3.7	29.0	51.8	15.5	.5	5.1	67.4	2.1	9.4	2.4	6,739	12,130	2,840
					2			30.1	53.8	16.1	.5	4.8	70.0	2.2	6.4	------	7,000	12,600	
					3			35.9	64.1	------	.6	5.8	83.4	2.6	7.6	------	8,344	15,020	

[1] A, mine sample collected by an engineer of the Bureau of Mines; B, mine sample collected by a geologist of the U. S. Geological Survey.
[2] 1, sample as received; 2, dried at a temperature of 105° C.; 3, moisture and ash free.
[3] Laboratory numbers with a prefix "W" represent samples analyzed in the Washington laboratory of the bureau; all others were analyzed in the Pittsburgh laboratory or at the fuel testing plant at St. Louis, Mo.
[4] Figures in this column represent temperature at which the cone of coal ash will fuse to a spherical lump when heated in a furnace in a slightly reducing atmosphere.

TABLE 3.--Analyses of mine samples from Pierce County, Washington coals (from Fieldner and others, 1931)--Continued

Location, county, and town	Mine	Bed	Location in mine	Sample			Proximate				Ultimate					Air-dry loss	Calorific value		Softening temperature °F.
				Kind	Condition	Laboratory No.	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen		Calories	British thermal units	
PIERCE COUNTY—continued																			
Carbonado	Carbon Hill	No. 11	40 feet above gangway	B	1	9570	4.5	28.5	47.5	19.5	.4	4.9	62.3	1.8	11.1	2.7	6,261	11,270	2,740
					2			29.8	49.8	20.4	.4	4.6	65.3	1.9	7.4		6,556	11,800	
					3			37.4	62.6		.5	5.7	82.0	2.3	9.5		8,233	14,820	
Do	Carbonade No. 4N.	Wilkeson	Rib, 16 chute below 14 counter.	A	1	10573	3.6	35.3	47.1	14.0	.3					2.2			2,330
Do	do	do	do	A	1	10574	3.8	35.6	46.6	15.0	.4					2.5			2,610
Do	do	do	Composite of 10573 and 10574.	A	1	10575	4.0	34.4	46.9	14.7	.3	5.6	67.4	1.9	10.1	2.4	6,800	12,240	
					2			35.8	48.9	15.3	.4	5.3	70.2	2.0	6.8		7,089	12,760	
					3			42.3	57.7		.4	6.3	83.0	2.3	8.0		8,367	15,060	
Do	Carbonado	Morgan	4 crosscut, 8 chute, upper bench.	A	1	A12431	1.5	32.5	49.7	16.3	.5					.3	6,917	12,450	2,740
Do	do	do	4 crosscut, 7 chute, lower bench.	A	1	A12432	1.4	29.0	43.9	25.7	.5					.0	6,028	10,850	2,800
Do	do	do	Composite of A12431 and A12432.	A	1	A12433	1.4	30.5	47.2	20.9	.5	4.7	64.7	1.9	7.3	.1	6,489	11,680	
					2			30.9	47.9	21.2	.5	4.6	65.6	1.9	6.2		6,583	11,850	
					3			39.2	60.8		.6	5.9	83.4	2.4	7.7		8,361	15,050	
Do	do	do	1 level, face, 13 chute, 1 counter.	A	1	A51187	2.5	29.9	50.8	16.8	0.5					1.5	6,850	12,330	2,790
Do	do	do	1 level, face, 11 chute	A	1	A51188	2.6	30.7	49.5	17.2	.5					1.5	6,783	12,210	2,510
Do	do	do	1 level, face, main rock tunnel.	A	1	A51189	3.9	28.5	46.8	20.8	.5					2.7	6,344	11,420	2,730
Do	do	do	Composite of A51187 to A51189.	A	1	A51190	3.0	29.7	49.0	18.3	.5	5.0	66.4	2.0	7.8	1.9	6,650	11,970	
					2			30.6	50.5	18.9	.5	4.8	68.5	2.0	5.3		6,856	12,340	
					3			37.8	62.2		.6	6.0	84.4	2.5	6.5		8,450	15,210	
Do	do	No. 4	Intersection of rock tunnel and bed.	A	1	A12435	1.6	32.3	46.0	20.1	.4	4.8	65.3	1.7	7.7	.3	6,478	11,660	2,660
					2			32.8	46.8	20.4	.5	4.7	66.3	1.7	6.4		6,583	11,850	
					3			41.2	58.8		.6	5.9	83.4	2.1	8.0		8,272	14,890	
Do	do	do	Top counter, 11 and 12 chutes.	A	1	A51191	2.7	31.4	51.4	14.5	.4					1.5	7,011	12,620	2,760
Do	do	do	3 crosscut, 10 and 11 chutes.	A	1	A51192	2.1	33.3	54.1	10.5	.4					1.0	7,472	13,450	2,510
Do	do	do	Face of counter, inby 16 chute.	A	1	A51193	2.4	31.0	51.5	15.1	.4					1.2	7,022	12,640	2,780
Do	do	do	Composite of A51191 to A51193.	A	1	A51194	2.3	31.8	52.6	13.3	.4	5.3	71.4	2.2	7.4	1.2	7,183	12,930	
					2			32.5	53.9	13.6	.4	5.1	73.0	2.3	5.6		7,350	13,230	
					3			37.6	62.4		.5	6.0	84.5	2.6	6.4		8,506	15,310	
Do	do	No. 8	1 level, 19 pillar, 3 crosscut.	A	1	A51195	3.0	32.1	48.9	16.0	.4					1.4	6,778	12,200	2,540
Do	do	do	1 west, face, counter, 31 chute.	A	1	A51196	3.3	31.7	49.8	15.2	.5					1.7	6,750	12,150	2,460
Do	do	do	1 west, face, 28 chute, above gangway.	A	1	A51197	3.1	32.8	50.2	13.9	.5					1.4	6,944	12,500	2,560
Do	do	do	Composite of A51195 to A51197.	A	1	A51198	3.1	32.3	49.6	15.0	.5	5.3	68.6	2.1	8.5	1.5	6,856	12,340	
					2			33.3	51.2	15.5	.5	5.1	70.8	2.2	5.9		7,072	12,730	
					3			39.5	60.5		.6	6.0	83.8	2.6	7.0		8,372	15,070	
Do	do	do	2 level south, 2 chute, Douty.	A	1	A61034	2.7	30.5	54.4	12.4	.6	5.3	71.7	2.3	7.7	2.0	7,122	12,820	
					2			31.3	56.0	12.7	.6	5.1	73.7	2.3	5.6		7,317	13,170	
					3			35.9	64.1		.7	5.9	84.4	2.7	6.3		8,383	15,090	
3 miles northwest of, at Orting.	Crocker	Crocker	Slope air course, 300 feet in.	A	1	A56771	12.4	35.6	39.9	12.1	.6	5.9	57.3	1.6	22.5	5.7	5,756	10,360	2,380
					2			40.6	45.6	13.8	.7	5.1	65.4	1.8	13.2		6,567	11,820	
					3			47.1	52.9		.8	5.9	75.8	2.1	15.4		7,617	13,710	
Fairfax:																			
¼ mile south of.	Fairfax	No. 1	South water-level counter, 5 and 6 chutes.	A	1	A56655	2.9	21.3	63.8	12.0	.7	4.9	74.1	2.5	5.8	2.3	7,356	13,240	2,450
					2			22.0	65.7	12.3	.7	4.8	76.3	2.6	3.3		7,572	13,630	
					3			25.1	74.9		.8	5.4	87.0	2.9	3.9		8,633	15,540	
Do	do	No. 2	North counter, 8 and 9 chutes.	A	1	A56644	3.3	19.6	61.0	16.1	.4					2.9	6,944	12,500	2,790
Do	do	do	North counter, 3 and 4 chutes.	A	1	A56645	2.8	21.1	66.5	9.6	.4					2.4	7,594	13,670	2,430
Do	do	do	Water-level counter, 12 and 13 chutes.	A	1	A56646	3.0	21.0	62.8	13.2	.4					2.6	7,211	12,980	2,400
Do	do	do	Composite of A56644 to A56646.	A	1	A56647	3.0	20.8	63.2	13.0	.4	4.9	73.4	2.2	6.1	2.6	7,261	13,070	
					2			21.4	65.2	13.4	.4	4.7	75.7	2.3	3.5		7,483	13,470	
					3			24.7	75.3		.5	5.4	87.5	2.6	4.0		8,644	15,560	
Do	do	No. 3	Below north water level, 8 chute.	B	1	9607	1.9	23.3	64.5	10.3	.5	5.0	77.2	2.1	4.9	.3	7,622	13,720	2,740
					2			23.7	65.8	10.5	.5	4.9	78.7	2.2	3.2		7,772	13,990	
					3			26.5	73.5		.6	5.5	87.9	2.4	3.6		8,683	15,630	
Do	do	Blacksmith	South end gangway from rock tunnel.	B	1	9609	3.3	21.0	63.0	12.7	.7	4.9	73.1	1.9	6.7	2.0	7,256	13,060	2,240
					2			21.7	65.1	13.2	.7	4.7	75.7	2.0	3.7		7,506	13,510	
					3			25.0	75.0		.8	5.4	87.1	2.3	4.4		8,639	15,550	
Do	do	No. 3	South counter, 19 and 20 chutes.	A	1	A56648	3.9	23.2	63.7	9.2	.5					3.5	7,589	13,660	2,390
Do	do	do	South counter, 12 and 13 chutes.	A	1	A56649	3.0	22.0	67.1	7.9	.5					2.6	7,756	13,960	2,390
Do	do	do	South counter, 1 and 2 chutes.	A	1	A56650	3.0	21.9	65.6	9.5	.5					2.5	7,633	13,740	2,370
Do	do	do	Composite of A56648 to A56650.	A	1	A56651	3.3	22.5	65.3	8.9	.5	5.2	77.7	2.1	5.6	2.9	7,650	13,770	
					2			23.3	67.5	9.2	.6	5.0	80.3	2.2	2.7		7,911	14,240	
					3			25.7	74.3		.6	5.5	88.5	2.4	3.0		8,717	15,690	
Do	do	No. 4	Water-level counter, 1 chute.	A	1	A56656	2.0	21.9	64.7	11.4	.6	5.2	75.8	2.2	4.8	1.5	7,494	13,490	2,370
					2			22.3	66.0	11.7	.6	5.0	77.3	2.3	3.1		7,650	13,770	
					3			25.3	74.7		.6	5.7	87.6	2.6	3.5		8,661	15,590	
Do	do	No. 5	South counter, 3 and 4 chutes.	A	1	A56652	2.9	21.2	64.6	11.3	.4					2.3	7,406	13,330	2,380
Do	do	do	South counter, 1 chute	A	1	A56653	3.4	20.7	65.4	10.5	.5					2.9	7,472	13,450	2,380

TABLE 3.--Analyses of mine samples from Pierce County, Washington coals (from Fieldner and others, 1931)--Continued

Location, county, and town	Mine	Bed	Location in mine	Sample			Proximate				Ultimate					Air-dry loss	Calorific value		Softening temperature °F.
				Kind	Condition	Laboratory No.	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen		Calories	British thermal units	
PIERCE COUNTY—continued																			
Fairfax—Contd.																			
¼ mile south of	Fairfax	No. 5	Composite of A56652 and A56653.	A	1	A56654	3.1	20.7	65.2	11.0	0.4	5.3	75.7	2.2	5.4	2.6	7,433	13,380	
					2			21.4	67.3	11.3	.5	5.1	78.1	2.3	2.7	-----	7,667	13,800	
					3			24.1	75.9	-----	.5	5.7	88.1	2.6	3.1	-----	8,650	15,570	
Do	do	No. 7	South and water-level gangway.	B	1	9608	2.8	18.5	45.4	33.3	.5	3.9	53.8	1.5	7.0	2.2	5,317	9,570	2,910
					2			19.0	46.8	34.2	.5	3.7	55.4	1.6	4.6	-----	5,472	9,850	
					3			28.9	71.1	-----	.7	5.6	84.2	2.4	7.1	-----	8,317	14,970	
1 mile south of	Montezuma	No. 1	North water level, 4 chute	B	1	9602	5.7	19.2	62.4	12.7	1.0	-----	-----	-----	-----	5.0	7,022	12,640	2,570
					2			20.4	66.1	13.5	1.0	-----	-----	-----	-----	-----	7,450	13,410	
Do	do	No. 2	Above 1 counter, 36 chute, water level.	B	1	9603	3.0	18.1	56.2	22.7	.7	-----	-----	-----	-----	2.3	6,250	11,250	2,880
					2			18.7	57.9	23.4	.7	-----	-----	-----	-----	-----	6,444	11,600	
Do	do	No. 3	11 chute, above water-level gangway.	B	1	9605	4.0	18.1	58.5	19.4	.5	-----	-----	-----	-----	3.3	6,567	11,820	2,430
					2			18.9	60.9	20.2	.5	-----	-----	-----	-----	-----	6,833	12,300	
Do	do	No. 4	2 counter, 6 chute	B	1	9606	2.6	21.0	65.6	10.8	.6	-----	-----	-----	-----	2.0	7,456	13,420	2,280
					2			21.6	67.3	11.1	.6	-----	-----	-----	-----	-----	7,650	13,770	
½ mile south of	Prospect No. 2	No. 2	35 feet from entry mouth	B	1	12495	2.6	24.8	52.8	19.8	.7	-----	-----	-----	-----	1.7	6,589	11,860	3,000
					2			25.5	54.1	20.4	.7	-----	-----	-----	-----	-----	6,761	12,170	
Do	Prospect No. 1	No. 1	do	B	1	12496	4.8	26.4	60.7	8.1	1.1	-----	-----	-----	-----	4.0	7,572	13,630	2,370
					2			27.7	63.8	8.5	1.2	-----	-----	-----	-----	-----	7,950	14,310	
2 miles south of	Prospect	Montezuma	45 feet from entry mouth	B	1	12478	3.6	20.6	41.9	33.9	.6	-----	-----	-----	-----	2.3	3,456	6,220	2,980
					2			21.4	43.4	35.2	.6	-----	-----	-----	-----	-----	3,583	6,450	
Melmont	Melmont	No. 1	End of north water-level gangway.	B	1	9577	9.2	9.4	63.7	17.7	.7	-----	-----	-----	-----	7.8	6,183	11,130	2,880
					2			10.3	70.2	19.5	.7	-----	-----	-----	-----	-----	6,806	12,250	
Do	do	No. 2	2 north chute, upper bench	B	1	9576	5.6	12.0	63.8	18.6	.4	-----	-----	-----	-----	4.4	6,444	11,600	2,910
Do	do	do	2 north chute, lower bench	B	1	9580	6.0	11.8	66.3	15.9	.4	-----	-----	-----	-----	4.5	6,628	11,930	2,850
Do	do	do	Composite of 9576 and 9580	B	1	10412	5.8	12.5	64.7	17.0	.4	4.1	68.6	1.7	8.2	4.5	6,544	11,780	-----
					2			13.3	68.6	18.1	.4	3.7	72.8	1.8	3.2	-----	6,944	12,500	
					3			16.3	83.7	-----	.5	4.5	88.9	2.2	3.9	-----	8,478	15,260	
Do	do	No. 3	Pillar, 1 north level, up dip	B	1	9578	3.1	21.4	60.6	14.9	.3	-----	-----	-----	-----	2.3	6,894	12,410	2,410
					2			22.1	62.5	15.4	.3	-----	-----	-----	-----	-----	7,111	12,800	
Do	do	do	1 north level, 50 feet above gangway.	B	1	9579	3.7	23.6	59.2	15.5	.4	5.0	71.6	1.7	7.8	2.9	7,083	12,750	2,750
					2			24.5	61.5	14.0	.4	4.7	74.3	1.8	4.8	-----	7,456	13,240	
					3			28.5	71.5	-----	.4	5.5	86.4	2.1	5.6	-----	8,550	15,390	
Pittsburg, ½ mile west of.	Black Carbon	Black Carbon	6 feet above gangway, 1,250 feet from mine mouth.	B	1	9892	5.1	32.8	39.1	23.0	.5	4.8	57.3	1.7	12.7	2.7	5,800	10,440	2,760
					2			34.6	41.2	24.2	.6	4.4	60.4	1.8	8.6	-----	6,111	11,000	
					3			45.6	54.4	-----	.8	5.8	79.7	2.4	11.3	-----	8,061	14,510	
Do	Pittsburg	Pittsburg	1 level gangway, beyond 13½ chute.	B	1	9894	4.7	32.7	42.2	20.4	.6	4.9	59.2	1.8	13.1	2.2	6,033	10,860	2,960
					2			34.3	44.3	21.4	.6	4.6	62.1	1.9	9.4	-----	6,328	11,390	
					3			43.7	56.3	-----	.7	5.8	79.0	2.5	12.0	-----	8,050	14,490	
Do	do	Lady Wellington	1 level, 1 crosscut, 32½ and 33 chutes.	B	1	9895	6.7	32.8	42.0	18.5	.4	5.0	58.9	1.6	15.6	3.5	5,911	10,640	3,000
					2			35.1	45.1	19.8	.4	4.6	63.1	1.8	10.3	-----	6,333	11,400	
					3			43.8	56.2	-----	.6	5.7	78.6	2.2	12.9	-----	7,900	14,220	
South Willis	South Willis	Windsor	Lower water-level gangway, beyond 11 chute.	B	1	9906	3.2	30.2	45.4	21.2	.4	4.8	62.6	1.6	9.4	1.4	6,244	11,240	2,300
					2			31.2	46.9	21.9	.4	4.6	64.6	1.6	6.9	-----	6,444	11,600	
					3			39.9	60.1	-----	.5	5.9	82.7	2.1	8.8	-----	8,250	14,850	
Wilkeson	Wilkeson	No. 1	1 south level, west dip	A	1	A52877	2.2	27.4	53.3	17.1	2.1	-----	-----	-----	-----	.8	6,794	12,230	2,450
Do	do	do	1 south gangway, 54 chute	A	1	A52878	2.0	28.4	56.4	13.2	1.8	-----	-----	-----	-----	1.1	7,289	13,120	2,330
Do	do	do	1 slope south, 52 chute	A	1	A52879	1.5	29.1	55.1	14.3	1.9	-----	-----	-----	-----	.9	7,189	12,940	2,500
Do	do	do	Composite of A52877 to A52879.	A	1	A52880	1.9	28.5	54.8	14.8	1.9	5.3	70.6	2.0	5.4	.9	7,004	12,770	
					2			29.0	56.0	15.0	2.0	5.1	72.0	2.0	3.9	-----	7,228	13,010	
					3			34.2	65.8	-----	2.3	6.1	84.7	2.3	4.6	-----	8,506	15,310	
Do	do	No. 2	East water level, lower bench.	B	1	9903	3.6	19.1	61.2	16.1	.5	4.4	70.5	1.9	6.6	2.8	6,844	12,320	2,720
					2			19.8	63.6	16.6	.5	4.2	73.1	2.0	3.6	-----	7,004	12,770	
					3			23.8	76.2	-----	.6	5.0	87.7	2.4	4.3	-----	8,517	15,330	
Do	do	do	East water level, upper bench.	B	1	9004	3.1	18.5	54.9	23.5	.4	-----	-----	-----	-----	2.3	6,128	11,030	2,760
					2			19.1	56.6	24.3	.4	-----	-----	-----	-----	-----	6,322	11,380	
Do	do	do	Southeast water level, 105 chute.	B	1	9905	3.7	27.1	56.6	12.6	.5	5.1	72.5	2.2	7.1	2.8	7,211	12,980	2,850
					2			28.1	58.8	13.1	.5	4.9	75.3	2.3	3.9	-----	7,489	13,480	
					3			32.3	67.7	-----	.5	5.6	86.7	2.6	4.6	-----	8,611	15,500	
Do	do	do	Gangway, 28 chute, 2 south slope.	A	1	A52876	2.5	27.8	56.4	13.3	.5	5.3	72.0	2.1	6.8	1.1	7,122	12,820	2,680
					2			28.5	57.8	13.7	.5	5.2	73.8	2.2	4.6	-----	7,300	13,140	
					3			33.0	67.0	-----	.6	6.0	85.5	2.5	5.4	-----	8,456	15,220	
Do	do	No. 3	Southeast gangway, 19 chute, lower bench.	B	1	9901	2.3	24.5	55.4	17.8	.5	-----	-----	-----	-----	1.2	6,811	12,260	2,970
					2			25.1	56.6	18.3	.5	-----	-----	-----	-----	-----	6,972	12,550	
Do	do	do	Southeast gangway, 19 chute, upper bench.	B	1	9902	2.5	27.7	61.3	8.5	.4	5.2	76.9	2.1	6.9	1.6	7,717	13,890	2,240
					2			28.4	62.8	8.8	.4	5.1	78.9	2.1	4.7	-----	7,917	14,250	
					3			31.1	68.9	-----	.5	5.6	86.5	2.3	5.1	-----	8,678	15,620	
Do	do	do	South end, east gangway	B	1	9000	5.3	20.4	59.3	15.0	.5	4.5	69.8	1.9	8.3	4.3	6,833	12,300	2,490
					2			21.6	62.6	15.6	.5	4.2	73.7	2.0	3.8	-----	7,217	12,990	
					3			25.6	74.4	-----	.6	4.9	87.6	2.4	4.5	-----	8,572	15,430	

TABLE 3.--Analyses of mine samples from Pierce County, Washington coals (from Fieldner and others, 1931)--Continued

Location, county, and town	Mine	Bed	Location in mine	Sample			Proximate				Ultimate					Air-dry loss	Calorific value		Softening temperature °F.
				Kind	Condition	Laboratory No.	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen		Calories	British thermal units	
PIERCE COUNTY—continued																			
Wilkeson	Wilkeson	No. 3	3 south gangway, 1 counter, 68 and 69 chute.	A	1	A52881	2.1	30.4	51.8	15.7	0.4					1.1	6,939	12,490	2,620
Do	do	do	1 south gangway, 64 chute, 9 and 10 crosscut.	A	1	A52882	2.7	30.4	52.3	14.6	.4					1.7	7,011	12,620	2,230
Do	do	do	66½ manway, 3 south gangway.	A	1	A52883	2.0	28.9	50.5	18.6	.5					.9	6,661	11,990	2,690
Do	do	do	Composite of A52881 to A52883.	A	1	A52884	2.3	30.2	51.2	16.3	.5	5.3	69.0	2.0	6.9	1.2	6,883	12,390	
					2			30.9	52.4	16.7	.5	5.2	70.6	2.1	4.9		7,044	12,680	
					3			37.1	62.9		.6	6.2	84.7	2.5	6.0		8,456	15,220	
Do	do	No. 4	1 level, 1 counter, 26½ and 27 chutes.	A	1	A52699	2.8	32.7	50.4	14.1	1.1					2.3	7,067	12,720	2,210
Do	do	do	1 south level, 6 crosscut, 18 and 19 breasts.	A	1	A52700	3.5	34.1	51.9	10.5	1.0					3.0	7,361	13,250	2,410
Do	do	do	1 south level, 12 crosscut, 18 and 19 breasts.	A	1	A52701	3.7	34.7	51.4	10.2	.8					2.9	7,372	13,270	2,330
Do	do	do	Composite of A52699 to A52701.	A	1	A52702	3.4	33.8	51.2	11.6	1.0	5.9	71.3	1.8	8.4	2.7	7,250	13,050	
					2			34.9	53.1	12.0	1.0	5.8	73.8	1.9	5.5		7,506	13,510	
					3			39.7	60.3		1.1	6.6	83.8	2.2	6.3		8,523	15,350	
Do	do	No. 7	100 feet south of rock tunnel.	B	1	9899	5.9	23.2	61.1	9.8	.4	5.1	74.0	2.2	8.5	4.9	7,317	13,170	2,380
					2			24.6	65.0	10.4	.4	4.7	78.7	2.3	3.5		7,778	14,000	
					3			27.5	72.5		.5	5.3	87.8	2.6	3.8		8,678	15,620	
Do	do	do	25 breast, 1 counter, 7 east gangway.	A	1	A52703	2.0	24.5	64.2	9.3	.5					1.6	7,672	13,810	2,410
Do	do	do	Face, 1 counter, 7 east gangway.	A	1	A52704	1.4	24.6	61.0	13.0	.8					1.0	7,344	13,220	2,700
Do	do	do	1 level, 25 breast, 7 east gangway.	A	1	A52705	3.0	24.4	58.8	13.8	.5					2.5	7,167	12,900	2,510
Do	do	do	Counter, 21 chute, 7 south gangway.	A	1	A52875	1.9	24.8	64.8	8.5	.4					.8	7,750	13,950	2,330
Do	do	do	Composite of A52703 to A52705 and A52875.	A	1	A52706	2.2	24.4	62.3	11.1	.6	5.2	75.4	2.2	5.5	1.5	7,483	13,470	
					2			24.9	63.7	11.4	.6	5.1	77.1	2.2	3.6		7,650	13,770	
					3			28.1	71.9		.7	5.8	86.9	2.5	4.1		8,628	15,530	
¼ mile west of	Brier Hill	Unnamed	500 feet south of water-level opening.	B	1	9897	4.7	29.8	37.0	28.5	1.2	4.3	52.4	1.7	11.9	2.3	5,300	9,540	2,700
					2			31.3	38.8	29.9	1.2	4.0	55.0	1.8	8.1		5,561	10,010	
					3			44.6	55.4		1.7	5.7	78.5	2.6	11.5		7,933	14,280	
Do	Gale Creek	No. 1	1 level air course, south of auxiliary slope.	B	1	9908	5.5	36.4	50.0	8.1	.8	5.7	71.2	1.9	12.3	3.4	7,233	13,020	2,300
					2			38.5	53.0	8.5	.9	5.4	75.4	2.0	7.8		7,656	13,780	
					3			42.1	57.9		.9	5.9	82.4	2.2	8.6		8,367	15,060	
Do	do	No. 2	2 level gangway, south of rock tunnel.	B	1	9909	3.9	35.0	55.1	6.0	1.0	5.6	75.0	2.0	10.4	2.4	7,639	13,750	2,390
					2			36.5	57.2	6.2	1.0	5.4	78.0	2.0	7.4		7,944	14,300	
					3			38.9	61.1		1.1	5.8	83.2	2.2	7.7		8,472	15,250	
Do	do	Queen	2 north level, pillar, 3 and 4 chutes.	B	1	9910	2.8	33.8	53.8	9.6	1.0	5.4	73.9	2.0	8.1	1.4	7,472	13,450	2,220
					2			34.8	55.4	9.8	1.0	5.3	76.0	2.1	5.8		7,689	13,840	
					3			38.5	61.6		1.2	5.9	84.3	2.3	6.3		8,528	15,350	
Do	do	do	1 north gangway, new slope.	A	1	W31921	2.4	35.7	52.1	9.8	.9						7,556	13,600	
Do	do	do	do	A	1	W31922	2.4	35.8	51.6	10.2	.9						7,500	13,500	
Do	do	do	16 breast, 1 north counter, new slope.	A	1	W31923	2.6	35.4	51.7	10.3	.8						7,461	13,430	
Do	do	do	do	A	1	W31924	2.6	35.3	52.1	10.0	.9						7,511	13,520	
Do	do	do	Pillar, 10 breast, 1 north gangway.	A	1	W31925	2.9	35.7	51.8	9.6	.7						7,517	13,530	
Do	do	do	do	A	1	W31926	2.7	35.8	51.9	9.6	.7						7,528	13,550	
Do	do	do	1 left air course, below 1 north gangway.	A	1	W32106	2.4	34.9	52.4	10.3	1.0						7,411	13,340	
Do	do	do	Pillar, 1 crosscut, 14 breast, 1 north.	A	1	W32107	2.6	35.5	53.1	8.8	1.0						7,583	13,650	
Do	do	do	Crosscut opposite 2 south gangway.	A	1	W32108	3.5	34.8	52.2	9.5	.9						7,422	13,360	
Do	do	do	Composite of W31921–W31926 and W32106–W32108.	A	1	W14390	1.9	35.1	53.1	9.9	.9	5.7	75.1	2.2	6.2		7,550	13,590	
					2			35.8	54.1	10.1	.9	5.6	75.6	2.2	4.6		7,694	13,850	
					3			39.8	60.2		1.0	6.3	85.1	2.5	5.1		8,556	15,400	
2 miles southeast of.	Snell	Snell	75 feet from entrance.	B	1														
					2	9896	6.7	25.8	50.0	17.5	.8					5.4	6,422	11,560	2,800
								27.6	53.7	18.7	.8						6,889	12,400	

TABLE 4.--Analyses of delivered coal from Pierce County, Washington (from Snyder and Plein, 1931)

Where mined: County and town	Where mined: Mine	Where mined: Bed	Size of coal	Approximate tons delivered	As-received—Moisture	Proximate analysis per cent, Dry coal: Volatile matter	Fixed carbon	Ash	Sulphur	Calorific value, per pound, As received: B. t. u.	Calories	Dry coal: B. t. u.	Calories	Moisture free and ash free: B. t. u.	Calories	Softening temperature, °F.	Number of analyses averaged	Place of delivery	Date of delivery
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
PIERCE COUNTY																			
Burnett	Burnett	Nos. 2 and 3	Lump	50	3.3	38.0	48.4	13.6	.4	12,520	6,956	12,950	7,194	14,990	8,328		1	Tipple (bins and cars at mine)	January, 1910.
Do	do	do	Steam (washed)	100	7.7	37.2	50.5	12.3	.6	12,310	6,839	13,340	7,411	15,210	8,450		1	do	Do.
Do	do	(Various)	Lump over 2-inch bar screen.	1,757	2.7	40.3	46.6	13.1	.9	12,600	7,000	12,940	7,189	14,890	8,272		16	Fort W. H. Seward, Alaska	1912-13.
Do	do	do	Lump	799	3.0	41.1	49.1	9.8	.7	12,980	7,211	13,380	7,433	14,820	8,233		11	Fort Liscum, Alaska	1911-12.
Do	do	do	do	1,050	2.4	39.5	46.7	13.8	1.0	12,620	7,011	12,930	7,183	15,000	8,333		10	Fort Lawton, Wash	1913-14.
Do	do	do	Run of mine	587	2.9	38.8	49.9	11.3	.8	12,860	7,144	13,250	7,361	14,930	8,204		12	Fort Stevens, Oreg	1911-12.
Do	do	do	do	147	3.7	39.3	48.7	12.0	.9	12,730	7,072	13,220	7,344	15,010	8,339		3	Fort Liscum, Alaska	1912-12.
Do	do	do	do	9,218	3.2	39.0	46.9	14.1	.9	12,450	6,917	12,860	7,144	14,970	8,317		20	Fort Liscum, Alaska, Fort Flagler, Wash., and U. S. Engineers, Oregon.	1913-14
Do	do	do	do	979	4.0	38.7	47.8	13.5	1.1	12,350	6,861	12,860	7,144	14,870	8,261		17	U. S. Veterans' Hospital, No. 77, Portland, Oreg.	1925-26.
Do	do	do	Steam (washed)	606	5.0	38.8	48.3	12.9	.9	12,430	6,906	13,080	7,267	15,020	8,344		10	Fort Stevens, Oreg	1912-13.
Do	do	do	do	933	4.5	38.4	48.0	13.6	1.1	12,390	6,883	12,970	7,206	15,020	8,344		6	do	1913-14.
Do	do	do	do	455	3.3	37.8	48.2	14.0	1.3	12,430	6,906	12,850	7,139	14,940	8,300		9	U. S. Veterans' Hospital, No. 77, Portland, Oreg.	1922-23.
Do	do	do	Steam (mixed)		4.5	38.3	47.4	14.3	1.3	12,350	6,861	12,930	7,183	15,090	8,383	2,390	1	Tipple	March, 1923
Carbonado	Carbonado	Morgan	Nut through 2½-inch and over ½-inch screens (washed).		1.9	32.0	53.1	14.9	.7	12,690	7,050	12,930	7,183	15,190	8,439	2,260	1	do	June, 1925.
Do	do	Morgan Nos. 4 and 5.	Nut through 2½-inch round-hole and over ⅝-inch square-hole screens (washed).	600	6.5	32.8	52.9	14.3	.5	12,190	6,772	13,040	7,244	15,220	8,456	2,780	1	do	Apr. 23, 1929.
Do	do	do	Buckwheat through ⅝-inch square-hole screen (washed).	550	9.5	33.1	54.3	12.6	.4	12,060	6,700	13,330	7,406	15,260	8,478	2,780	1	do	Do.
Do	Carbon Hill-Carbonado (mines).	Wingate	Lump over 3-inch screen	130	3.2	37.1	53.2	9.7	.6	13,320	7,400	13,760	7,644	15,240	8,467		2	do	December, 1909.
Do	do	do	Lump over 1¼-inch bar screen.	2,321	2.9	40.3	50.5	9.2	.6	13,200	7,333	13,590	7,550	14,970	8,317		26	Fort Lawton, Wash., and Fort Liscum, Alaska.	1912-13.
Do	do	do	Steam (washed)	650	4.9	33.2	53.9	12.9	.9	12,490	6,939	13,130	7,294	15,070	8,372		2	Tipple	December, 1909.
Do	do	do	Steam (washed)	5,207	4.5	37.2	51.8	11.0	0.7	12,710	7,061	13,310	7,394	14,960	8,311		46	Fort Stevens, Oreg., and Q. M. depot, Seattle, Wash.	1911-13.
Do	do	do	do	8,880	5.3	36.5	50.4	13.1	.7	12,340	6,856	13,030	7,239	14,900	8,328		42	Seattle or Tacoma, Wash	1912-13.
Do	do	do	do	2,479	5.1	37.5	49.2	13.3	.6	12,240	6,800	12,900	7,167	14,880	8,267		19	Q. M. depot, Seattle, Wash	1913-14.
Do	do	No. 3	Run of mine	50	4.7	30.5	52.8	16.7	.5	12,130	6,739	12,730	7,072	15,390	8,494		1	Denver testing plant	1908.
Do	do	(Various)	Lump over 2-inch screen	300	4.7	32.1	51.4	16.5	.5	11,860	6,589	12,440	6,911	14,900	8,278		2	Tipple	December, 1909.
Do	do	do	Lump over 1½-inch screen.	2,602	4.8	37.1	50.2	12.7	.6	12,360	6,867	12,980	7,211	14,870	8,261		23	Vancouver Barracks and Fort Lawton, Wash., and Fort Stevens, Oreg.	1916-17.
Fairfax	Fairfax	No. 3	Slack through 1½-inch screen (washed).		3.5	23.4	66.7	9.9	.5	13,520	7,511	14,010	7,783	15,550	8,639		1	Tipple (bunkers at mine)	December, 1910.
Do	do	Nos. 2, 3, and 5.	Nut and slack through 2-inch round-hole screen (washed).	100	4.6	21.5	60.8	17.7	.5	12,090	6,717	12,680	7,044	15,400	8,556	2,810	1	Tipple	July 9, 1929.
Do	Montezuma	No. 2	Nut and slack through 1½-inch screen (washed).	50	6.7	19.0	58.3	22.7	.8	11,050	6,139	11,840	6,578	15,320	8,511		1	do	December, 1909.
Do	do	Nos. 3 and 4	do	50	5.4	21.0	65.9	13.1	.5	12,880	7,156	13,610	7,561	15,660	8,700		1	do	Do.
Melmont	Melmont	Nos. 2 and 3	Steam (washed)	400	7.1	22.0	57.8	20.2	.4	11,330	6,294	12,200	6,778	15,290	8,494		1	do	Do.
Pittsburg	Pittsburg	Lady Wellington and Pittsburg.	do	100	7.8	33.9	44.0	22.1	.4	10,270	5,706	11,140	6,189	14,300	7,944		1	do	January, 1910.
South Willis	Willis	Windsor and No. 1.	Nut and slack through 1½-inch screen (washed).	50	7.1	30.6	45.2	24.2	.5	10,380	5,767	11,170	6,206	14,740	8,189		1	do	December, 1909.
Wilkeson	Gale Creek	Queen	Lump	798	2.6	36.1	52.5	11.4	.9	18,330	7,406	13,690	7,606	15,450	8,583		12	Fort Stevens, Oreg	1912-13.
Do	do	do	Nut and slack through 2½-inch screen (washed).	895	2.8	35.4	53.4	11.2	.9	13,260	7,367	13,650	7,583	15,370	8,539		13	Tipple	June, 1912.
Do	do	do	do	895	3.9	36.3	52.0	11.7	.9	13,090	7,272	13,620	7,567	15,420	8,567		4	Navy Department, Tacoma, Wash	July, 1912.
Do	do	do	Steam	592	5.6	36.2	51.3	12.5	.9	12,600	7,050	13,440	7,467	15,350	8,528		13	Fort Stevens, Oreg	1912-13.
Do	Wilkeson	Nos. 3, 4, and 7.	Nut through 3-inch round-hole and over ½-inch square-hole screen (washed).	50	2.1	32.2	55.0	12.8	.9	13,150	7,306	13,430	7,461	15,400	8,556	2,450	1	Tipple	July 3, 1929.
Do	do	do	Steam, crushed to ½-inch square-hole screen (washed).	50	3.6	31.1	54.0	14.9	.9	12,560	6,978	13,030	7,239	15,320	8,511	2,690	1	do	July 5, 1929.
Do	do	do	Coking through ½-inch square-hole screen (washed).	40	7.8	32.0	54.7	13.3	.9	12,250	6,806	13,280	7,378	15,330	8,517	2,820	1	do	July 6, 1929.
Do	do	do	Gas through ½-inch square-hole screen (washed).	100	7.5	31.2	54.8	14.0	.7	12,210	6,783	13,190	7,328	15,350	8,528	2,620	1	do	July 5, 1929.
Do	do	Nos. 2, 3, and 7.	Slack through 1¾-inch screen (rewashed).		6.6	25.0	60.5	14.5	.5	12,330	6,850	13,200	7,333	15,440	8,578		1	Tipple (bins at mine)	January, 1910.

TABLE 5.--Analyses of mine, tipple, and delivered samples of Pierce County, Washington coals from Abernethy and others (1958)

County, town, and mine	Bed	Rank	Size or other description	Kind of sample	Condition	Agglomerating index	Proximate, percent: Moisture	Proximate, percent: Volatile matter	Proximate, percent: Fixed carbon	Proximate, percent: Ash	Ultimate, percent: Sulfur	Ultimate, percent: Hydrogen	Ultimate, percent: Carbon	Ultimate, percent: Nitrogen	Ultimate, percent: Oxygen	Calorific value, B.t.u.	Fusibility of ash: Initial deformation temperature, °F.	Fusibility of ash: Softening temperature, °F.	Fusibility of ash: Fluid temperature, °F.	Mineral-matter-free basis: Fixed carbon, dry basis, percent	Mineral-matter-free basis: Calorific value: B.t.u., dry basis	Mineral-matter-free basis: Calorific value: B.t.u., moist basis	Laboratory No. or index No.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
PIERCE COUNTY																							
Carbonado:																							
Carbonado			Run-of-mine	D	1		2.1	34.1	50.0	13.8	2.5					12,740							109
				7	2			34.8	51.1	14.1	2.6					13,010							
Do.			do.	D	1		2.0	34.1	49.2	14.7	.9					12,600							110
				2	2			34.8	50.2	15.0	.9					12,860							
Do.			do.	D	1		4.2	33.7	46.3	15.8	.5					11,930							111
				2	2			35.2	48.3	16.5	.5					12,450							
Wilkeson:																							
Bartoy	No. 2, east dip	Hvab		M	1	Cg	5.2	27.4	53.0	14.4	.7	5.2	68.1	2.0	9.6	12,240	2,470	2,520	2,600	67.1	15,480	14,520	B53204
					2			28.8	56.0	15.2	.7	4.8	71.8	2.1	5.4	12,900							
					3			34.0	66.0		.8	5.7	84.7	2.5	6.3	15,220							
Do.	do.	Hvab		M	1	Cg	4.6	28.0	55.7	11.7	.5					12,930	2,910+			67.4	15,650	14,820	B53205
Do.	do.	Hvab		M	1	Cg	4.8	27.0	54.0	14.2	.6					12,380	2,630	2,710	2,820	67.8	15,530	14,840	B53206
Do.	do.	Hvab	Composite of B53204, B53205, and B53206.	M	1	Cg	4.8	27.4	54.0	13.8	.5	5.2	69.4	2.0	9.6	12,500				67.4	15,590	14,710	B53207
					2			28.8	56.7	14.5	.6	4.9	72.9	2.1	5.0	13,130							
					3			33.7	66.3		.7	5.5	85.3	2.4	5.8	15,350							
Champion	Champion	Hvab		M	1	Cg	4.7	30.1	44.3	20.9	.8	5.0	62.6	1.5	9.2	11,320	2,520	2,650	2,750	61.1	15,600	14,650	C54014
					2			31.6	46.4	22.0	.8	4.7	65.8	1.6	5.1	11,890							
					3			40.5	59.5		1.0	6.0	84.3	2.0	6.7	15,220							
East Miller No. 8	No 8 (Miller), east dip		1¼-inch lump	T	1	Cg	2.3	26.9	56.8	14.0	1.5	4.9	71.6	2.0	6.0	12,820	2,290	2,330	2,440				B95270
					2			27.6	58.0	14.4	1.6	4.7	73.3	2.0	4.0	13,120							
					3			32.2	67.8		1.8	5.5	85.6	2.4	4.7	15,330							
Do.	do.		1¼-inch by 0	T	1	Cg	5.7	25.2	51.6	17.5	1.6					11,770	2,220	2,310	2,570				B95271
					2			26.7	54.7	18.6	1.7					12,490							
Skookum	No. 3, west dip	Hvab		M	1	Cg	1.1	28.4	55.9	14.6	.4	4.9	72.5	2.1	5.5	12,920	2,470	2,620	2,780	67.2	15,500	15,300	C16487
					2			28.7	56.6	14.7	.5	4.9	73.3	2.1	4.5	13,060							
					3			33.7	66.3		.5	5.7	86.0	2.5	5.3	15,320							
Sparton	Champion	Hvab		M	1	Cf	4.1	35.9	46.0	14.0	.7	5.3	67.5	1.9	10.6	12,280	2,420	2,590	2,730	57.1	15,230	14,490	D31102
					2			37.4	48.0	14.6	.8	5.1	70.4	2.0	7.1	12,800							
					3			43.8	56.2		.9	6.0	82.4	2.3	8.4	14,990							
Wilkeson-Miller	No. 5 (Miller), west dip.	Hvab		M	1	Cg	5.0	36.7	52.2	6.1	.7	6.0	74.7	2.2	10.3	13,600	2,340	2,460	2,690	59.2	15,480	14,650	B53925
					2			38.7	54.9	6.4	.7	5.8	78.7	2.3	6.1	14,380							
					3			41.3	58.7		.8	6.1	84.1	2.4	6.6	15,360							
Do.	do.	Hvab		M	1	Cg	3.7	36.3	53.2	6.8	1.3					13,720	2,080	2,250	2,680	60.1	15,470	14,850	B53926
Do.	do.	Hvab	Composite of B53925 and B53926.	M	1	Cg	4.4	36.5	52.6	6.5	1.0	5.9	74.9	2.1	9.6	13,680				59.5	15,480	14,760	B53927
					2			38.2	55.0	6.8	1.0	5.6	78.3	2.2	6.1	14,320							
					3			41.0	59.0		1.1	6.0	84.1	2.4	6.4	15,370							
Wilkeson-Wingate	No. 4 (Wingate), east dip.	Mvb	2-inch lump	M	1	Cg	2.4	21.3	57.3	19.0	2.7	4.5	68.0	1.8	4.0	12,120	2,210	2,260	2,380	78.3	15,860	15,570	D26934
					2			21.9	58.7	19.4	2.8	4.3	69.7	1.9	1.9	12,420							
					3			27.1	72.9		3.5	5.4	86.5	2.4	2.2	15,410							
Do.	do.	Mvb		M	1	Cg	2.6	21.8	59.3	18.3	2.4	4.6	70.5	1.9	4.3	12,530	2,100	2,230	2,490	75.1	15,810	15,310	D26935
					2			22.4	60.9	16.7	2.4	4.4	72.3	2.0	2.2	12,870							
					3			26.9	73.1		2.9	5.3	86.9	2.3	2.6	15,460							
Do.	do.	Mvb	2-inch lump	T	1	Cg	3.9	21.6	57.1	17.4	.9					12,170	2,210	2,540	2,710	74.2	15,790	15,620	B95268
					2			22.5	59.4	18.1	1.0					12,660							
Do.	do.		2-inch by 0	T	1	Cg	7.8	20.4	56.3	15.5	.8	5.0	66.9	1.7	10.1	11,840	2,400	2,740	2,680				B95269
					2			22.1	61.1	16.8	.9	4.5	72.5	1.9	3.4	12,840							
					3			26.6	73.4		1.1	5.4	87.2	2.2	4.1	15,430							
Do.	No. 4 (Winrate)		1¼-inch by 0	D	1		4.8	25.8	51.6	17.8	2.1					11,830		2,310					112
				16	2			27.1	54.2	18.7	2.2					12,430		16					
Do.	do.		do.	D	1		5.3	25.0	52.9	16.8	2.2					11,950		2,300					113
				14	2			26.4	55.9	17.7	2.3					12,620		13					
Do.	do.		do.	D	1		7.3	23.9	52.9	15.9	2.1					11,830		2,300					114
				16	2			25.8	57.0	17.2	2.3					12,760		16					
Do.	do.		do.	D	1		5.0	24.0	54.3	16.7	2.3					12,030							115
				1	2			25.3	57.1	17.6	2.4					12,600							

EXPLANATION OF SYMBOLS USED IN TABLE OF ANALYSES

Mvb—medium-volatile bituminous.
Hvab—high-volatile A bituminous.

M, mine sample; T, tipple sample; D, delivered coal.
The bold-faced figure indicates the number of deliveries averaged.

1, Sample as received; 2, dried at 105° C.; 3, moisture- and ash-free.

Softening temperature, bold-faced figure indicates the number of deliveries averaged.

Cf—fair caking.
Cg—good caking.

Specific gravity of coal.--Table 6 gives the true specific gravities of several mine and tipple samples of Wilkeson-Carbonado coals determined by the standard method (Fieldner and Selvig, 1951). The specific gravity is given for the dry coal, and for convenience of comparison the dry-ash value also is given. The proximate and ultimate analyses of these coals are given in table 5.

TABLE 6.--True specific gravities of several Pierce County, Washington coals from Abernethy and Hartner (1958)

County and town	Mine	Bed	Kind of sample[1]	Size of sample	Dry ash	Specific gravity	Laboratory No.
1	2	3	4	5	6	7	8
PIERCE COUNTY							
Wilkeson	Bartoy	No. 2, east dip	M		15.2	1.39	B53204
Do	do	do	M		12.3	1.35	B53205
Do	do	do	M		14.9	1.38	B53206
Do	Champion	Champion	M		22.0	1.44	C54014
Do	East Miller No. 5	No. 5 (Miller), east dip.	T	1⅝-inch lump	14.4	1.40	B95270
Do	do	do	T	1⅝-inch by 0	18.6	1.42	B95271
Do	Skookum	No. 3, west dip	M		14.7	1.38	C16487
Do	Sparton	Champion	M		14.6	1.38	D31102
Do	Wilkeson-Miller	No. 5 (Miller), west dip.	M		6.4	1.29	B53925
Do	do	do	M		7.1	1.31	B53926
Do	Wilkeson-Wingate	No. 4 (Wingate), east dip.	T	2-inch lump	18.1	1.43	B95268
Do	do	do	T	2-inch by 0	16.8	1.42	B95269

[1] M, mine sample; T, tipple sample.

Friability of coal.--The relative friability of several coals in the Wilkeson-Carbonado coal field is shown in table 7. Friability refers to the degree of reduction in size of freshly-mined coal as a result of work done by external forces, such as impact and attrition (Yancey and others, 1932, p.18). Different coal beds in the same mine may differ considerably in the friability of coal as is shown for the Wilkeson mine in table 7. Samples collected from four beds in the mine gave a range of friability from 61.7 to 84.6 percent. The No. 4 coal bed was the least friable. Many of the bituminous coals of Washington are more friable than the average Eastern bituminous coal (Yancey and others, 1932, p.39).

TABLE 7.--Results of friability tests of mine samples of coal
(from Yancey and others, 1932, table 2)

Laboratory No. of composite analysis sample	Mine	Bed	Composite analysis sample: As-received moisture, per cent	Composite analysis sample: As-received ash free: Fixed carbon, per cent	Composite analysis sample: As-received ash free: British thermal units	Ash, per cent	Size of screen retained on, per cent: 1.05-inch	0.742-inch	0.525-inch	0.371-inch	4-mesh	8-mesh	14-mesh	28-mesh	48-mesh	100-mesh	200-mesh	Through 200-mesh screen	Friability, per cent	Slacking index
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
BITUMINOUS																				
Washington:																				
A52706	Wilkeson	No. 7	2.2	70.1	15,150	7.2	5.7	8.1	5.5	3.1	1.4	1.5	5.4	12.2	17.4	14.3	9.8	15.6	83.2	
Do	do	do				8.0	2.5	11.0	5.1	2.6	2.0	2.7	4.3	12.3	17.0	13.8	10.7	16.0	84.6	
Average																			83.9	2.3
A52880	do	No. 1	1.9	64.3	14,990	12.6	10.8	13.1	5.2	1.2	1.2	.7	1.6	7.1	17.3	12.4	10.7	18.7	76.0	2.7
A52884	do	No. 3	2.3	61.2	14,800	12.5	11.3	12.2	2.5	1.8	1.6	1.1	2.7	11.6	18.3	11.6	9.8	14.5	76.8	0
A52702	do	No. 4	2.4	57.9	14,760	14.0	18.6	20.7	6.5	2.1	2.2	.7	.5	1.5	6.9	10.1	10.3	18.9	61.7	.8
	do	Tipple (nut)				11.4	25.9	21.4	4.9	2.9	.4	.2	.2	.3	2.8	11.4	10.0	19.6	55.3	
	do	do				15.3	25.6	25.3	2.0	2.0	.6	.3	.2	.4	2.0	11.2	8.9	19.5	54.1	
Average																			54.7	
Washington:																				
A51194	Carbonado	No. 4	2.3	60.7	14,910	6.0	12.5	6.5	2.6	1.9	1.2	1.8	7.7	14.8	17.9	12.3	7.7	12.1	78.8	
Do	do	do				6.2	14.8	8.7	5.3	2.2	1.9	1.1	1.8	7.6	17.2	14.5	9.8	14.1	74.1	
Average																			76.5	2.8
A51190	do	Morgan	2.0	60.0	14,630	7.9	1.4	9.6	10.0	4.4	4.1	2.8	5.7	11.5	17.1	12.3	8.3	12.8	83.1	
Do	do	do				8.7	4.3	6.3	8.5	6.4	7.2	4.5	6.9	9.6	14.1	11.2	8.0	13.0	81.7	
Average																			82.4	1.3
A51196	do	No. 5	2.1	58.4	14,520	9.6	29.2	8.5	7.9	2.7	2.3	.6	.7	2.6	10.7	10.9	3.6	14.3	58.6	
Do	do	do				11.0	28.2	8.9	7.6	2.7	2.3	1.2	1.7	2.8	10.8	10.9	3.1	14.8	59.4	
Average																			59.0	1.3
Washington:																				
A56769	Black Carbon	Peacock	4.7	53.2	13,670	17.3	37.1	22.1	6.0	2.7	2.9	.5	.4	.6	2.4	6.4	6.4	12.4	42.4	1.6
A56770	do	No. 10	4.5	53.7	12,630	18.6	80.3	0	0	0	.1	.1	.1	.1	.6	2.6	4.6	10.5	19.6	.8
A56324	Hi-Carbon	Hi-Carbon	6.7	49.9	12,900	9.9	53.3	8.5	2.4	1.2	.8	.1	.2	.7	2.6	6.6	6.9	14.7	38.2	
Do	do	do				10.7	46.2	9.1	2.8	2.1	.9	.3	.4	1.7	6.1	8.2	7.4	14.8	44.7	
Average																			41.5	2.8
SEMIBITUMINOUS																				
Washington:																				
A56655	Fairfax	No. 1	2.9	72.5	15,050	11.6	0	0	5.6	8.6	7.2	6.3	9.6	12.7	15.3	10.3	8.4	16.0	90.6	0
A56647	do	No. 2	2.0	72.6	15,020	6.9	8.7	1.3	2.1	2.4	2.6	4.2	12.7	17.3	17.5	10.1	7.8	13.3	85.9	
Do	do	do				7.1	0	7.7	5.1	2.3	6.2	4.2	8.4	13.9	16.9	11.3	8.5	14.5	87.8	
Average																			86.9	2.3
A56651	do	No. 3	2.3	71.7	15,120	9.2	7.3	13.0	6.7	3.5	.9	.2	.5	4.5	16.0	14.9	12.8	19.7	78.2	
Do	do	do				9.0	8.2	12.8	3.1	2.3	1.1	.7	1.9	9.3	16.6	13.5	10.9	19.6	79.4	
Average																			78.8	2.5
A56656	do	No. 4	2.0	73.0	15,230	11.9	21.5	8.8	1.4	.5	.4	.2	.6	5.3	16.0	12.4	10.8	22.1	70.4	0
A56654	do	No. 5	2.1	73.3	15,030	8.7	0	10.8	7.5	6.7	4.3	2.0	2.3	8.8	15.4	13.0	10.2	18.0	84.3	
Do	do	do				9.7	2.2	8.7	9.4	4.5	2.4	1.8	2.6	9.6	15.8	12.3	10.4	18.3	83.6	
Average																			84.0	0

Melmont area

Location and coal-bearing sequence

The Melmont area is south of the Wilkeson-Carbonado area and although some of the mine workings at Melmont are within three-fourths of a mile of the southern part of the Carbonado area (fig. 9), the stratigraphic relations between the two areas cannot be determined with certainty. Daniels (1914, p. 41) pointed out that the coal beds of the Melmont area seem to underlie the coal beds of the Carbonado area and are probably in the lower part of the Carbonado Formation.

A generalized section of the principal coal beds in the Melmont area is given in figure 20. Coal reserves have been estimated for seven coal beds in the area. These beds range from 3 to 13 feet in thickness. Sections of coal measured in the Melmont area are shown in figure 21. Most of the coal produced in the area came from the Melmont Nos. 5 and 6.

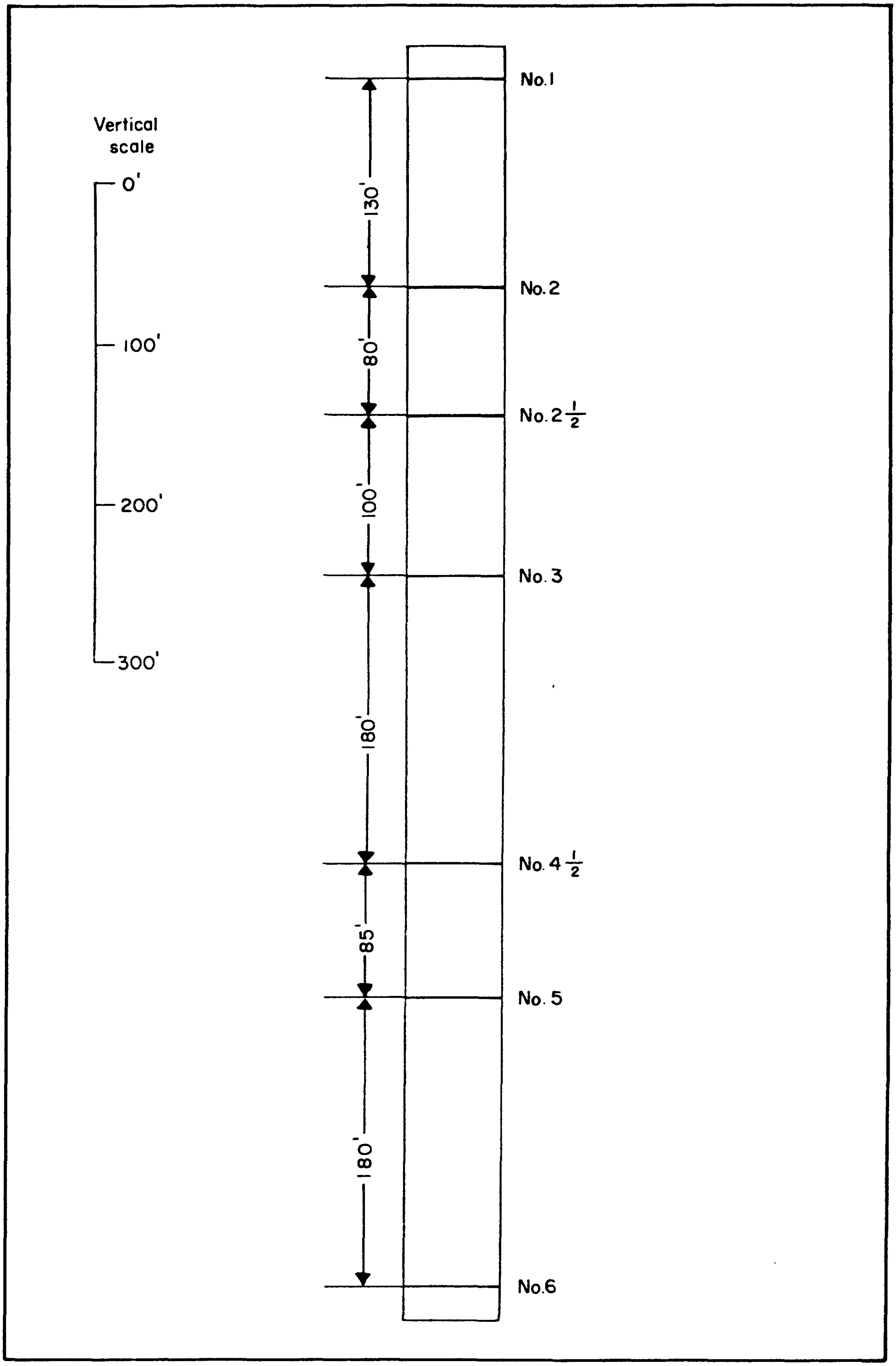

Figure 20.—Generalized section of principal coal beds in the Melmont area, Pierce County, Washington
(From Beikman and others, 1961, p. 69)

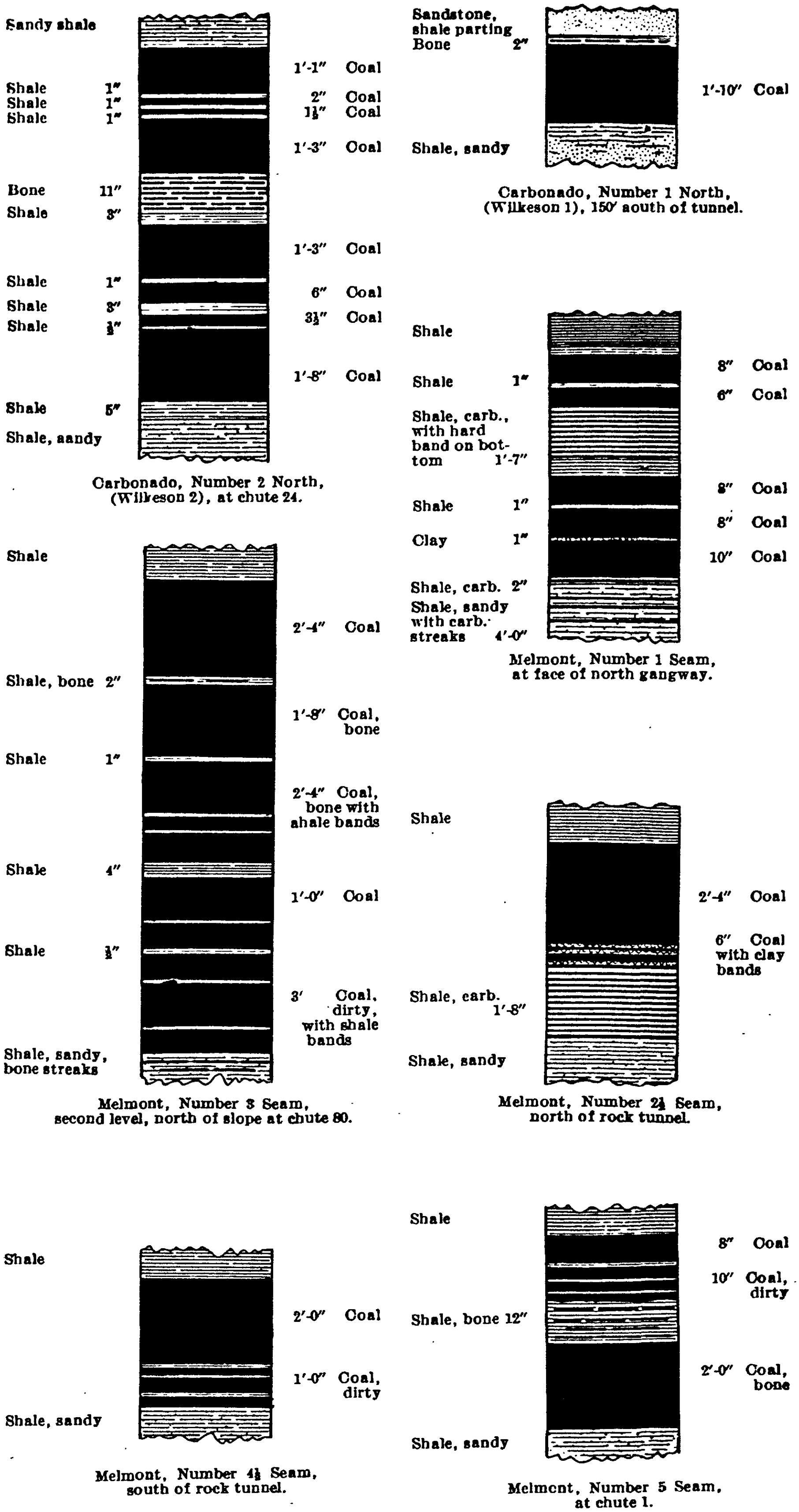

FIGURE 21.-- Sections of coal in the Carbonado Formation at Melmont (from Daniels,1914, p. 74-75)

Structural attitude of coal beds

Maps of the mine workings reveal complexities of structure in secs. 9, 10, 15, and 16, T. 18 N., R. 6 E. In the NE car. sec. 21, T. 18 N., R. 6 E., the Melmont tunnel (Blossberg tunnel) was driven 1,600 feet eastward from the tracks of the now abandoned Northern Pacific Railroad on the east side of the Carbon River. The tunnel intersected a high-angle reverse fault about 275 feet from the portal and then crossed steeply dipping beds that exhibit small tightly folded and faulted anticlines and synclines (Gard, 1968, p. B26). The average dip of the coal beds in the area is 55°.

The largest igneous intrusive body in the coal field crops out in the Carbon Gorge west of the Melmont area in secs. 16 and 21, T. 18 N., R. 6 E. It is composed of quartz diabase and forms a sill at least 950 feet thick that can be traced along the gorge for nearly 3 miles.

Physical and chemical properties

Only six analyses of the coal beds in the Melmont area are available. These few analyses indicate that the coals rank from medium-volatile to low-volatile bituminous and that the area contains the highest rank coal found in Pierce County (Beikman and others, 1961, p. 67). The ash content of the coal ranges from 14.9 percent to 18.6 percent and averages about 17 percent which is somewhat higher than the average ash content of the coals in the Wilkeson-Carbonado area. The moisture content of the coals in the Melmont area ranges from 3.1 to 9.2 percent and averages about 6 percent. The sulfur content ranges from 0.3 to 0.7 percent and averages 0.5 percent. Average analyses of the Melmont coals are given in table 8. Analyses of mine samples of coals in the Melmont area are given in table 3.

Table 8.—Averages of analyses (as-received basis) of coal samples from the Melmont area, Pierce County, Washington

(M—moisture; VM—volatile matter; FC—fixed carbon; Btu—British thermal units. Source of analyses is Fieldner and others, 1931.)

Coal bed	Proximate (percent)				Sulfur (percent)	Btu	Number of analyses used in obtaining average
	M	VM	FC	Ash			
No. 1 --------	9.2	9.4	63.7	17.7	0.7	11,130	1
No. 2 --------	5.8	12.1	64.9	17.2	.4	11,770	3
No. 3 --------	3.4	22.5	59.9	15.2	.4	12,580	2

(From Beikman and others, 1961, p. 79)

Table 9.—Averages of analyses (as-received basis) of coal samples from the Fairfax-Montezuma and Ashford areas, Pierce County, Washington

(M—moisture; VM—volatile matter; FC—fixed carbon; Btu—British thermal units. Sources of analyses are Fieldner and others, 1931; and Cooper and Abernethy, 1941.)

Location			Mine or prospect	Coal bed	Proximate (percent)				Sulfur (percent)	Btu	Number of analyses used in obtaining average
Sec.	T.	R.			M	VM	FC	Ash			
26	18 N.	6 E.	Fairfax -------	No. 3 (McNeill) --	1.9	23.3	64.5	10.3	0.5	13,720	1
				Blacksmith --------	3.3	21.0	63.0	12.7	.7	13,050	1
34	18 N.	6 E.	-----do------	No. 1 -----------	2.9	21.3	63.8	12.0	.7	13,240	1
				No. 2 -----------	3.0	20.6	63.4	16.3	.4	13,050	3
				No. 3 -----------	3.3	22.5	65.5	8.2	.5	13,787	3
				No. 4 -----------	2.0	21.9	64.7	11.4	.6	13,490	1
				No. 5 -----------	3.1	20.9	65.0	10.9	.4	13,390	2
			Prospect ------	No. 1 -----------	4.8	26.4	60.7	8.1	1.1	13,630	1
				No. 2 -----------	2.6	24.8	52.8	19.8	.7	11,860	1
2	17 N.	6 E.	Montezuma ---	No. 1 -----------	5.7	19.2	62.4	12.7	1.0	12,640	1
				No. 2 -----------	3.0	18.1	56.2	22.7	.7	11,250	1
				No. 3 -----------	4.0	18.1	58.5	19.4	.5	11,820	1
				No. 4 -----------	2.6	21.0	65.6	10.8	.6	13,420	1
15	15 N.	6 E.	Ashford -------	Nisqually ---------	5.8	15.3	64.7	24.2	.4	10,410	1

(From Beikman and others. 1961. p. 79)

Fairfax-Montezuma area

Location and coal-bearing sequence

The Fairfax-Montezuma area occupies the southern part of the Wilkeson-Carbonado coal field. In the past, mines were opened north and south of the Carbon River in the vicinity of Fairfax, in secs. 26, 27, and 34, T. 18 N., R. 6 E. The Montezuma area is just south of the map area (pl. 1) in sec. 2, T. 17 N., R. 6 E. The coal beds in these two areas occur in the lower part of the Carbonado Formation, but the stratigraphic relations between these areas and the more productive mines in the Wilkeson-Carbonado area have not been determined.

More than six coal beds have been opened or mined at Fairfax and Montezuma, however, the total number of beds present is unknown. Although the mine workings are close together, the complexities of the structure and lack of data make correlation of coal beds between the mines impossible (Beikman and others, 1961, p. 79). It is generally agreed that the coal beds in this area lie stratigraphically below the coal beds in the Wilkeson-Carbonado area. Sections of coal in the Carbonado Formation at Montezuma and Fairfax are shown on figure 22.

Structural attitude of coal beds

The mine workings and scattered prospects in the Fairfax-Montezuma area indicate that numerous small north-trending anticlines and synclines are present and that the strata are cut by many faults. The dip of the coal beds is usually more than 60°. Mine workings at Fairfax penetrated gravel on both the north and south sides of the Carbon River, indicating that the coal beds have been eroded to an undetermined depth along the present river channel (Beikman and others, 1961, p. 79).

Physical and chemical properties

The coal in the Fairfax Montezuma area is of medium-volatile bituminous rank and is reported to have coking qualities. The ash content of the coal ranges from 7.9 to 22.7 percent and averages 14 percent. The moisture content ranges from 1.9 to 5.7 percent and averages about 3 percent; and the sulfur content ranges from 0.4 to 1.1 percent and averages 0.6 percent (Beikman and others, 1961, p. 83). Average analyses of coals in the Fairfax-Montezuma area are given in table 9; analyses of mine and delivered samples of coal are given in tables 3 and 4.

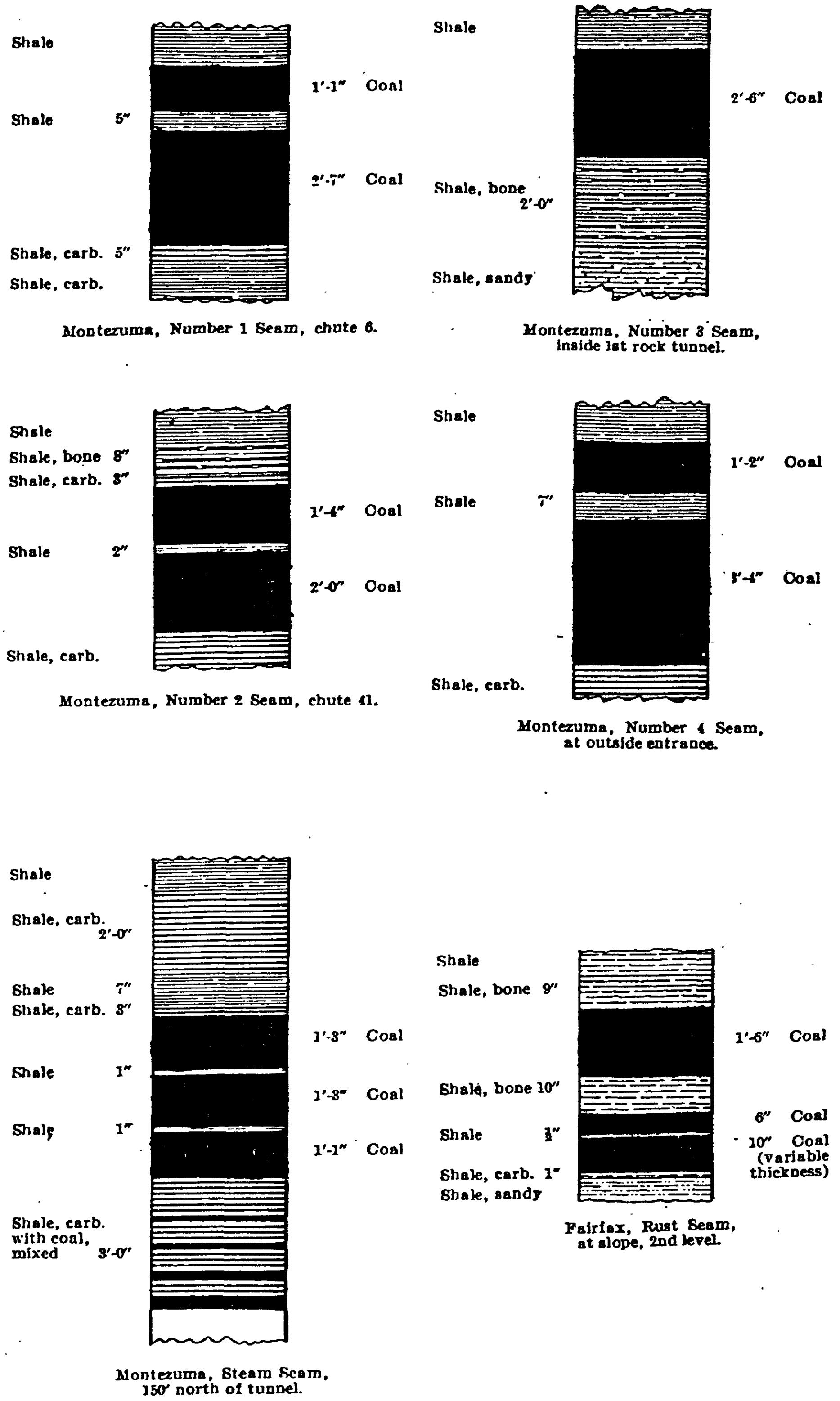

FIGURE 22.--Sections of coal in the Carbonado Formation at Montezuma and Fairfax (from Daniels, 1914, p. 75)

Spiketon area

Location and coal-bearing sequence

The Spiketon area is about 2 miles northeast of Wilkeson and includes the mines at Spiketon (formerly known as Black Carbon and Pittsburg), which are located north of South Prairie Creek in E 1/2 sec. 15, T. 19 N., R. 6 E.; and, the South Willis mines, which are south of South Prairie Creek in the E 1/2 sec. 22, T. 19 N., R. 6 E. (pl. 1, fig. 9). More than 10 coal beds are present in the Spiketon area. These beds occur in the upper part of the Puget Group, in the Spiketon Formation, and thus lie stratigraphically above the coal beds in the Carbonado Formation which were mined in the Wilkeson-Carbonado area.

The coal beds in the Spiketon Formation lie at or near the surface in a northwestward-trending belt about three-quarters of a mile wide on the eastern margin of the Wilkeson-Carbonado coal field. The formation is absent in the western part of the field. Volcanic rocks in the lower part of the Ohanapecosh Formation overlie the coal-bearing strata of the Spiketon Formation along the eastern margin of the coal field. Locally, a thin tongue of volcanic sedimentary rocks in the Northcraft Formation underlie the Spiketon Formation. The Spiketon is about 3,600 feet thick and includes the upper part of the Burnett Formation of Willis and Smith (1899, p. 8).

The ten or more coal beds in the Spiketon area range from a few inches to as much as 11 feet in thickness. The average thickness of the Nos. 6, 7, and 8, and 10 beds, which have been mined to the greatest extent, is about 4 feet (Beikman and others, 1961, p. 67). The correlation of the beds at Spiketon with those at South Willis is shown in figure 23, wherein, the coal beds designated by numbers are at Spiketon and those designated by names are at South Willis. A generalized columnar section of the Spiketon Formation is shown in figure 24; sections of coal measured in the mines of the Spiketon area are shown in figures 25 and 26.

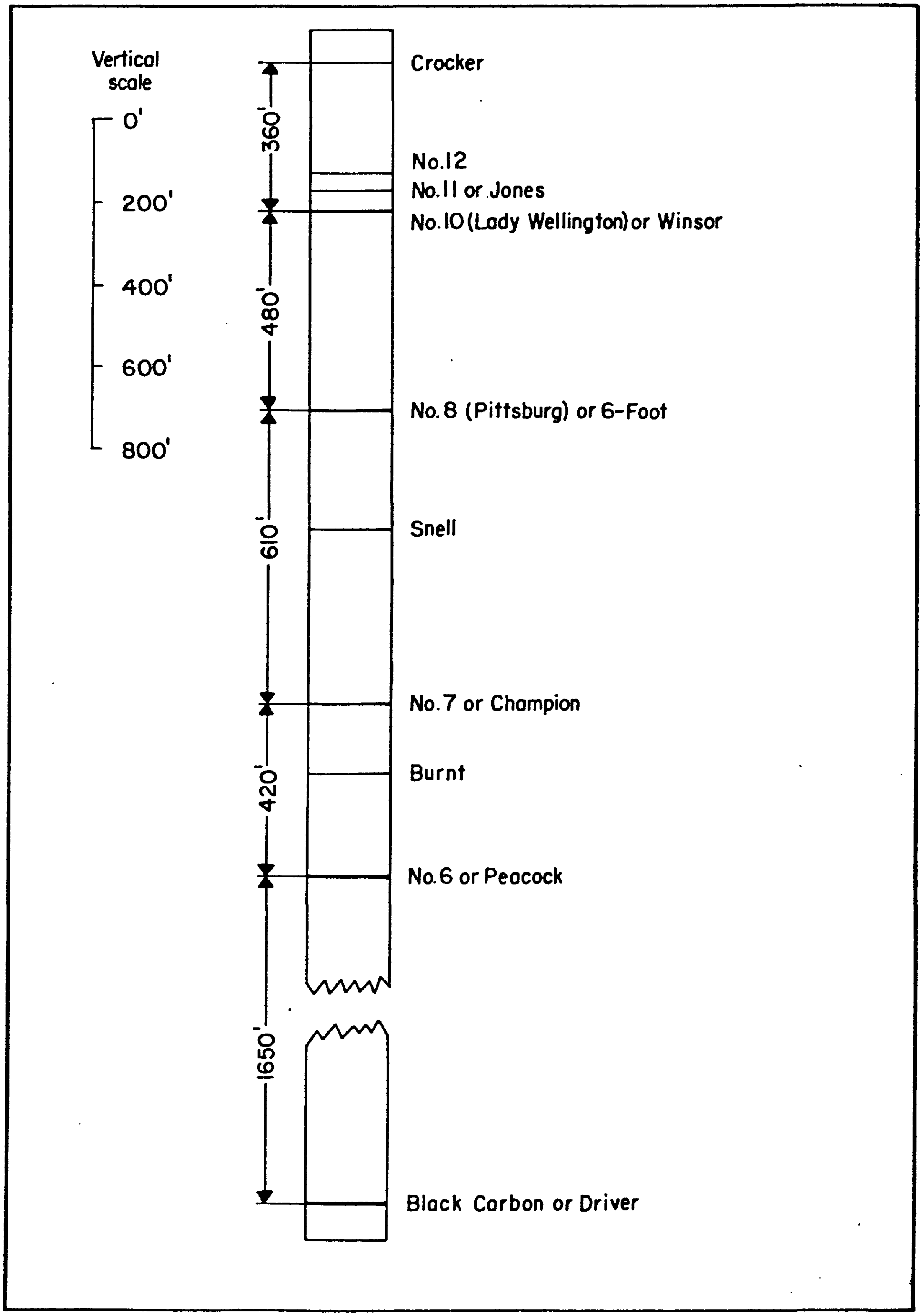

Figure 23.-Generalized section of principal coal beds in the Spiketon area, Pierce County, Washington
(From Beikman and others, 1961, p. 68)

page 61 follows

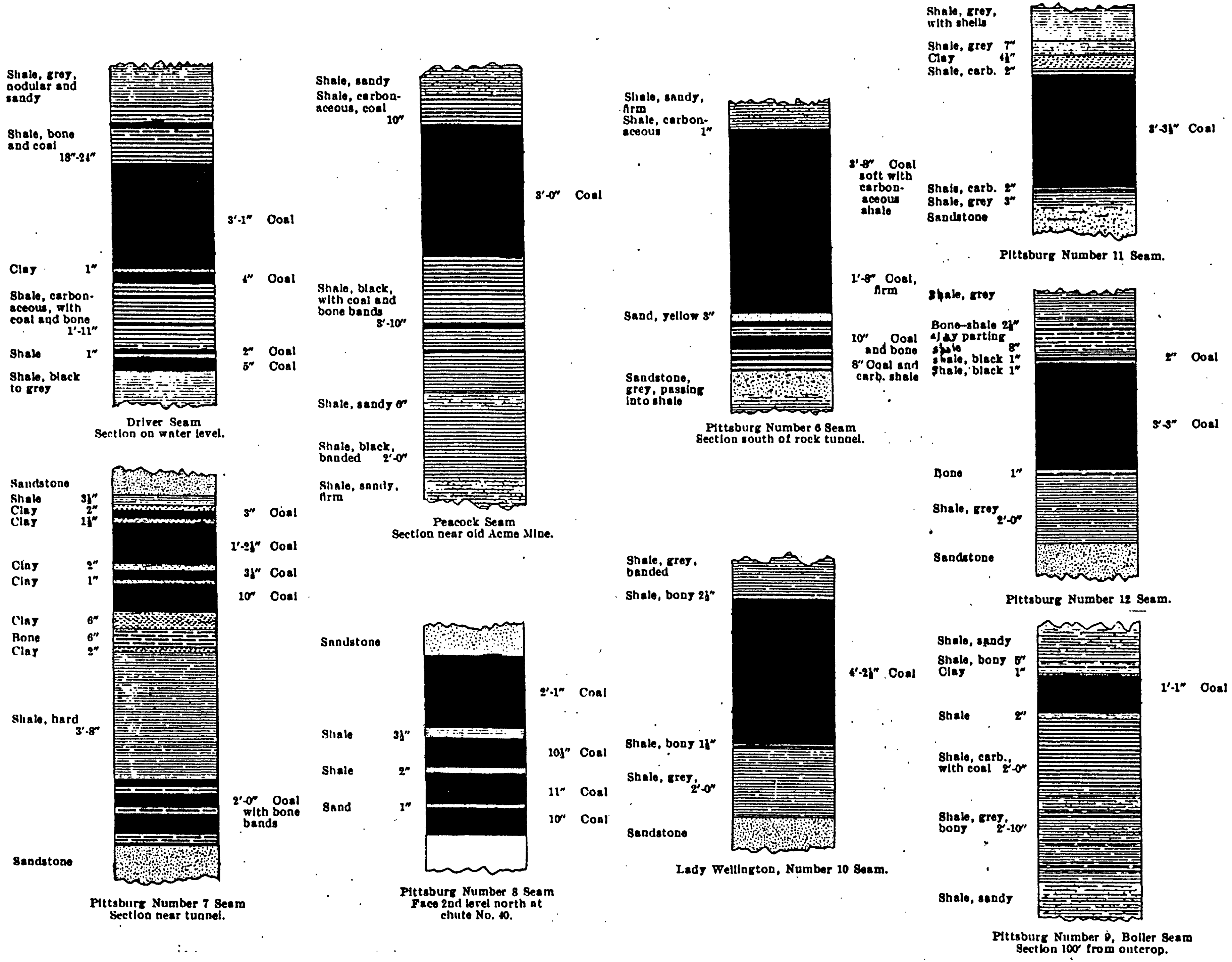

FIGURE 25.--Sections of coal beds in the Spiketon Formation at Spiketon mines

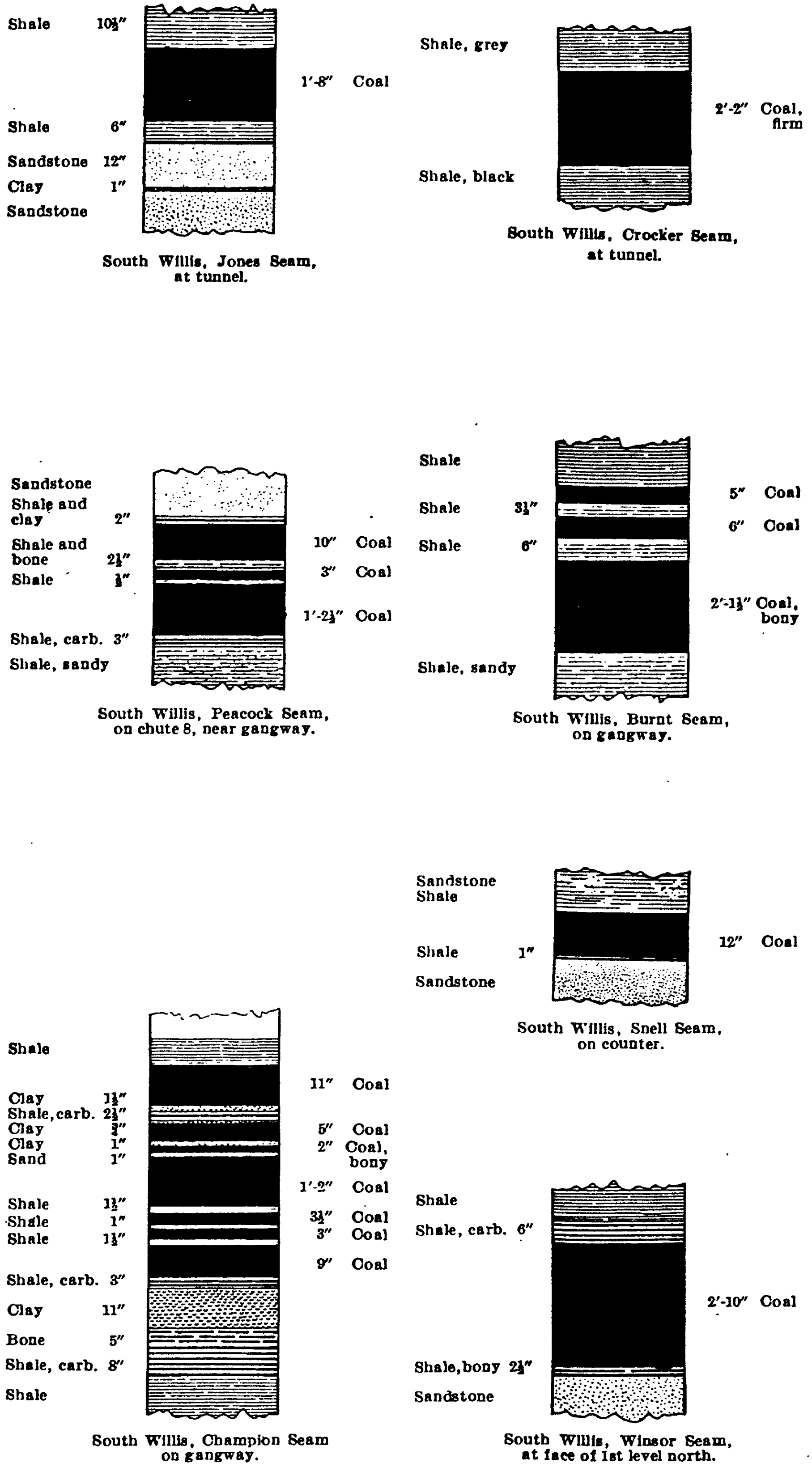

FIGURE 26.-- Sections of coal beds in the Spiketon Formation at South Willis Mines
(from Daniels, 1914, p. 58-59)

Structural attitude of coal beds

The coal-bearing strata of the Spiketon area are on the east flank of the Wilkeson anticline. All of the coal beds in the area maintain a fairly uniform dip of about 60° to the east. Small igneous dikes and sills are fairly common in the upper part of the Spiketon Formation and several have been encountered in the mine workings at Spiketon and South Willis.

Physical and chemical properties

The coal in the Spiketon area is of high-volatile A bituminous rank. It is generally free burning and noncoking, and has a relativelv higher ash content than the older coal in the Wilkeson-Carbonado area. The ash content ranges from 17.5 to 22.9 percent and averages 20 percent. The moisture content ranges from 3.2 to 6.7 percent and averages 5 percent. The sulfur content ranges from 0.4 to 0.8 percent and averages 0.6 percent (Beikman and others, 1961, p. 67). Analyses of the coal beds in the Spiketon area are given in tables 3, 4, and 10.

Table 10.—Averages of analyses (as-received basis) of coal samples from the Spiketon area, Pierce County, Washington

(M—moisture; VM—volatile matter; FC—fixed carbon; Btu—British thermal units. Source of analyses is Fieldner and others, 1931.)

Coal bed	Proximate (percent)				Sulfur (percent)	Btu	Number of analyses used in obtaining average
	M	VM	FC	Ash			
No. 10 or Winsor	4.91	31.46	43.80	19.82	0.41	10,938	2
No. 8 or Pittsburg	4.69	32.71	42.22	20.38	.55	10,856	1
Snell	6.70	25.71	50.10	17.50	.78	11,560	1
Black Carbon	5.08	32.82	39.14	22.96	.54	10,442	1

(From Beikman and others, 1961, p. 67)

Puyallup-Ashford Coal Field

The coal-bearing sequence in the Wilkeson-Carbonado coal field is probably continuous across concealed areas south of Fairfax and Montezuma and is thought to extend to Ashford, about 18 miles south of Fairfax. The sedimentary rocks between the Fairfax-Montezuma and Ashford areas are known to contain coal beds, but data concerning their extent and thickness are lacking. The coal-bearing area south of Fairfax is collecttively known as the Puyallup-Ashford field (Daniels, 1914, p. 9). At Ashford the strata have been greatly faulted and are intruded by igneous rocks. Although numerous coal beds are believed to occur near Ashford, only the Nisqually coal bed was mined commercially. The Nisqually coal is of high-volatile A bituminous rank, and is as much as 10 feet thick in places.

Coal Resources

Wilkeson-Carbonado coal field

The most comprehensive summary of the coal resources of the Wilkeson-Carbonado coal field was prepared by Beikman and others in 1961. They reported that the total resources of coal remaining in the ground in Pierce County, Washington, as of January 1, 1960, are estimated to be 362 million tons. Of this total, about 349 million tons is estimated to be in the Wilkeson-Carbonado coal field as defined in this report; and the remainder, about 13 million tons, is estimated to be in the Ashford area, about 18 miles south of the Wilkeson-Carbonado coal field. The reserve base of the Wilkeson-Carbonado coal field is summarized in table 16.

Wilkeson-Carbonado area

The reserve bases were estimated for nine coal beds in the Wilkeson-Carbonado area. Several additional coal beds are present in the area, but because their thickness is unknown they could not be included in the reserve base estimates. The location and classification of the coal reserve base by individual beds is shown on figures 27 through 35.

The reserve base of coal remaining in the ground in the Wilkeson-Carbonado area is estimated to total 222 million tons. About 32 percent of the reserve base is classified as measured and indicated, and 68 percent as inferred (Beikman and others, 1961, p. 66). The reserve base figures by township and bed are shown in table 11.

In the accompanying figures and tables the reserve base is termed reserve. This difference in classification is the result of a recent decision by the Bureau of Mines and Geological Survey to revise their nomenclature. The term reserve base is used to designate coal that is well-known and deemed minable at the present. Reserve designates that part of the minable coal that can be economically, legally, and technologically recovered at the present. Reserve equals recoverable reserves of previous usage.

Spiketon area

The reserve base of coal remaining in the ground in the Spiketon area is estimated to total 88.8 million tons. About 54 percent of the reserve base is classified as measured and indicated, and 46 percent as inferred (Beikman and others, 1961, p. 67). The location and classification of the coal reserve base in the Spiketon area by individual beds shown on figures 27 through 35; the reserve base by township and bed is shown in table 12.

Melmont area

The coal reserve bases were estimated for seven coal beds in the Melmont area and the total reserve base of coal remaining in the ground is estimated to be about 16 million tons. About 10 percent of the reserve base is classified as measured and indicated, and 90 percent as inferred (Beikman and others, 1961, p. 67). The location and classification of the coal reserve base by individual beds is shown in figures 27 through 33; the reserve base figures by township and bed are shown in table 13.

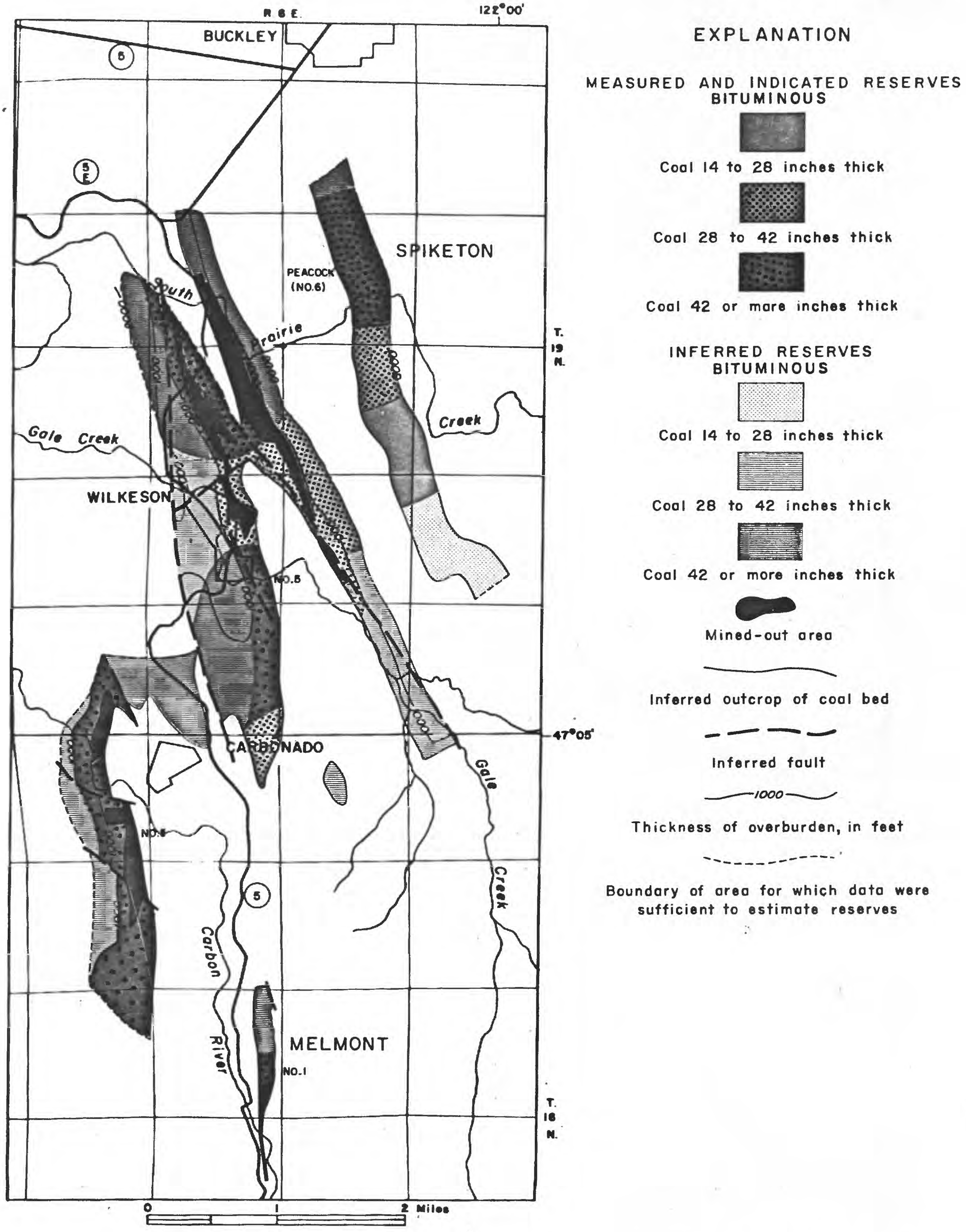

FIGURE 27.–GENERALIZED MAP OF THE NO. 1 BED OF MELMONT, NO. 5 BED OF WILKESON, AND PEACOCK (NO. 6) BED OF SPIKETON
(From Beikman and others, 1961, p. 70)

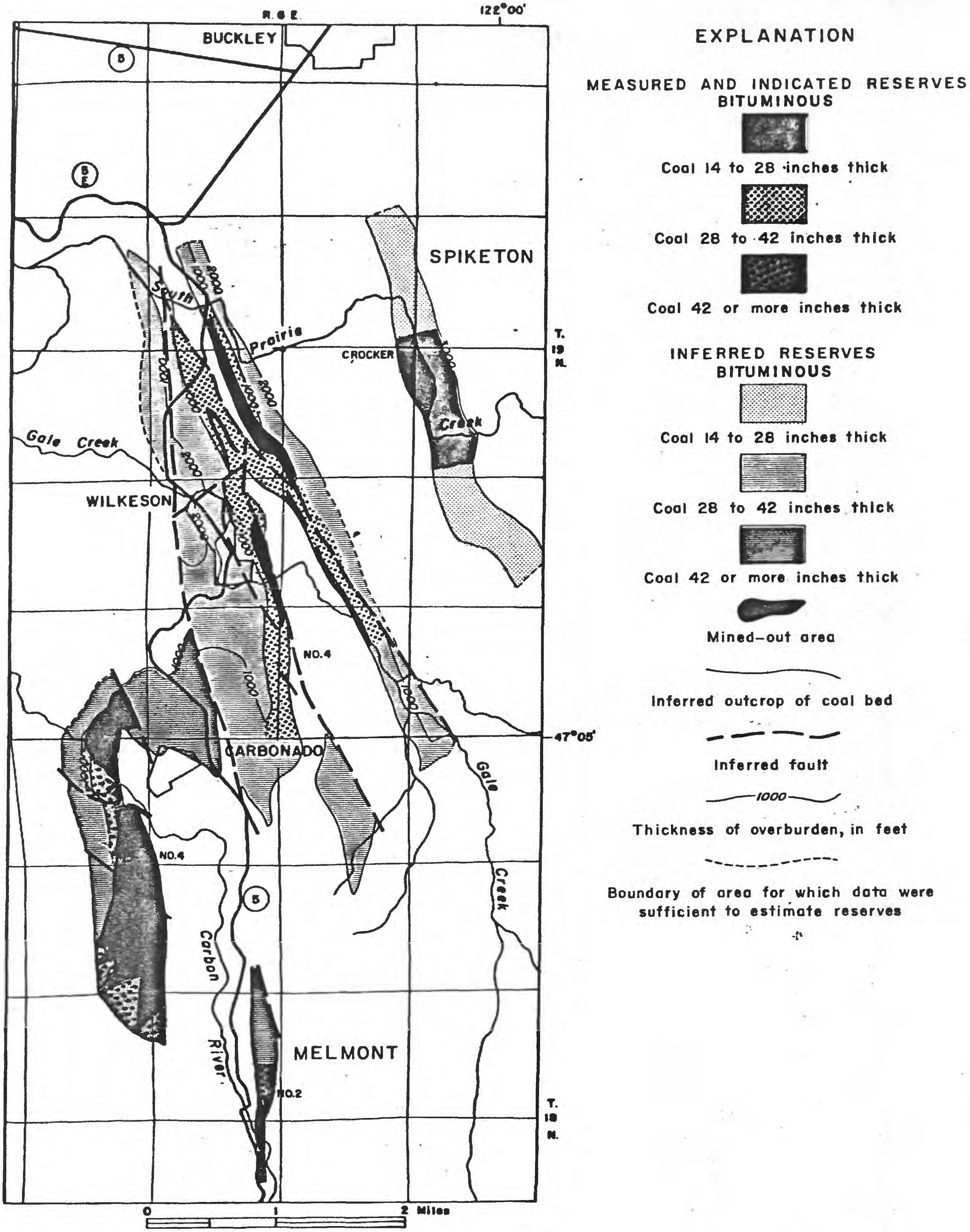

FIGURE 28.—GENERALIZED MAP OF THE NO. 2 BED OF MELMONT, NO. 4 BED OF WILKESON, AND CROCKER BED OF SPIKETON

(From Beikman and others, 1961, p. 71)

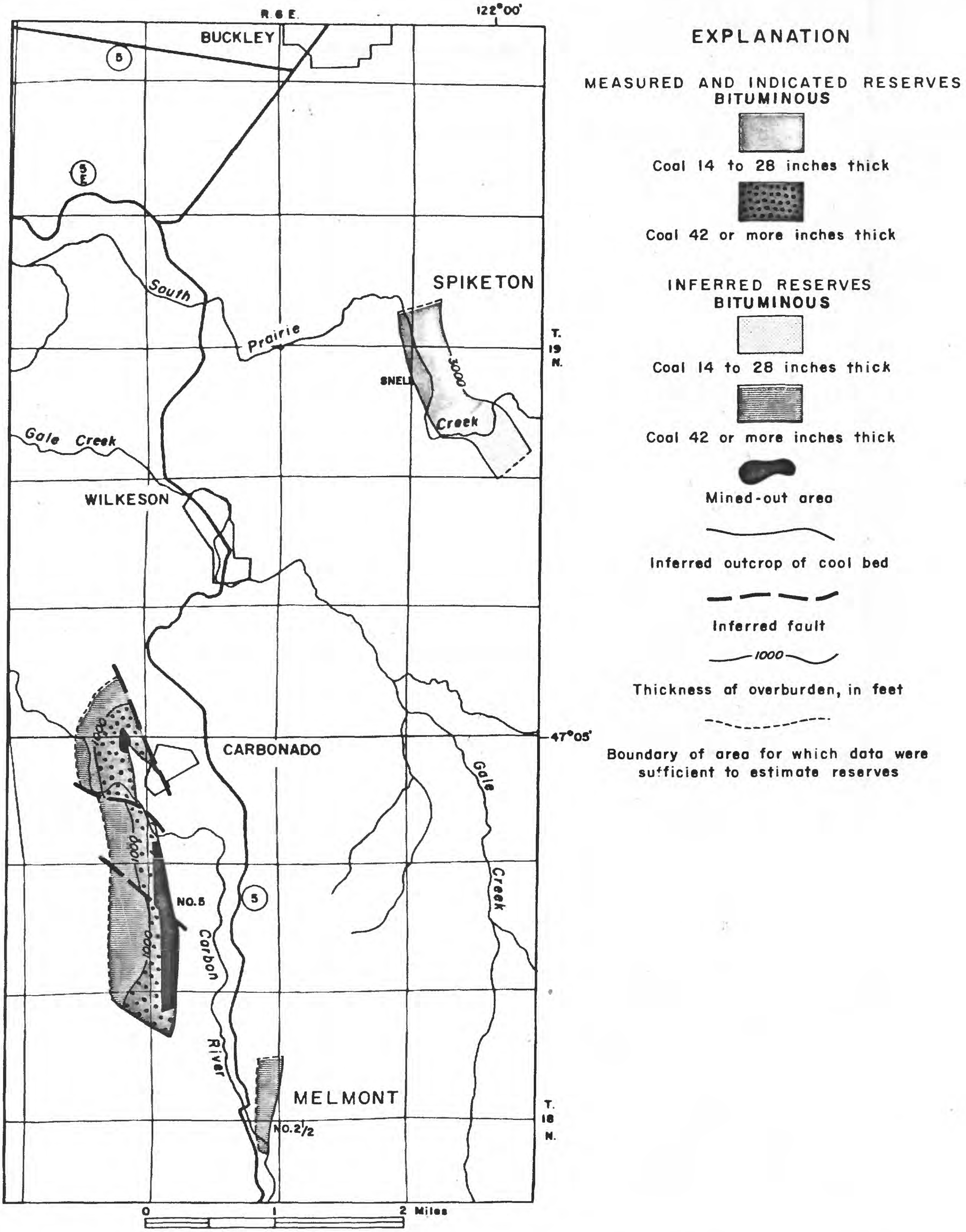

FIGURE 29.—GENERALIZED MAP OF THE NO. 2½ BED OF MELMONT, NO. 5 BED OF CARBONADO, AND SNELL BED OF SPIKETON
(From Beikman and others, 1961, p. 72)

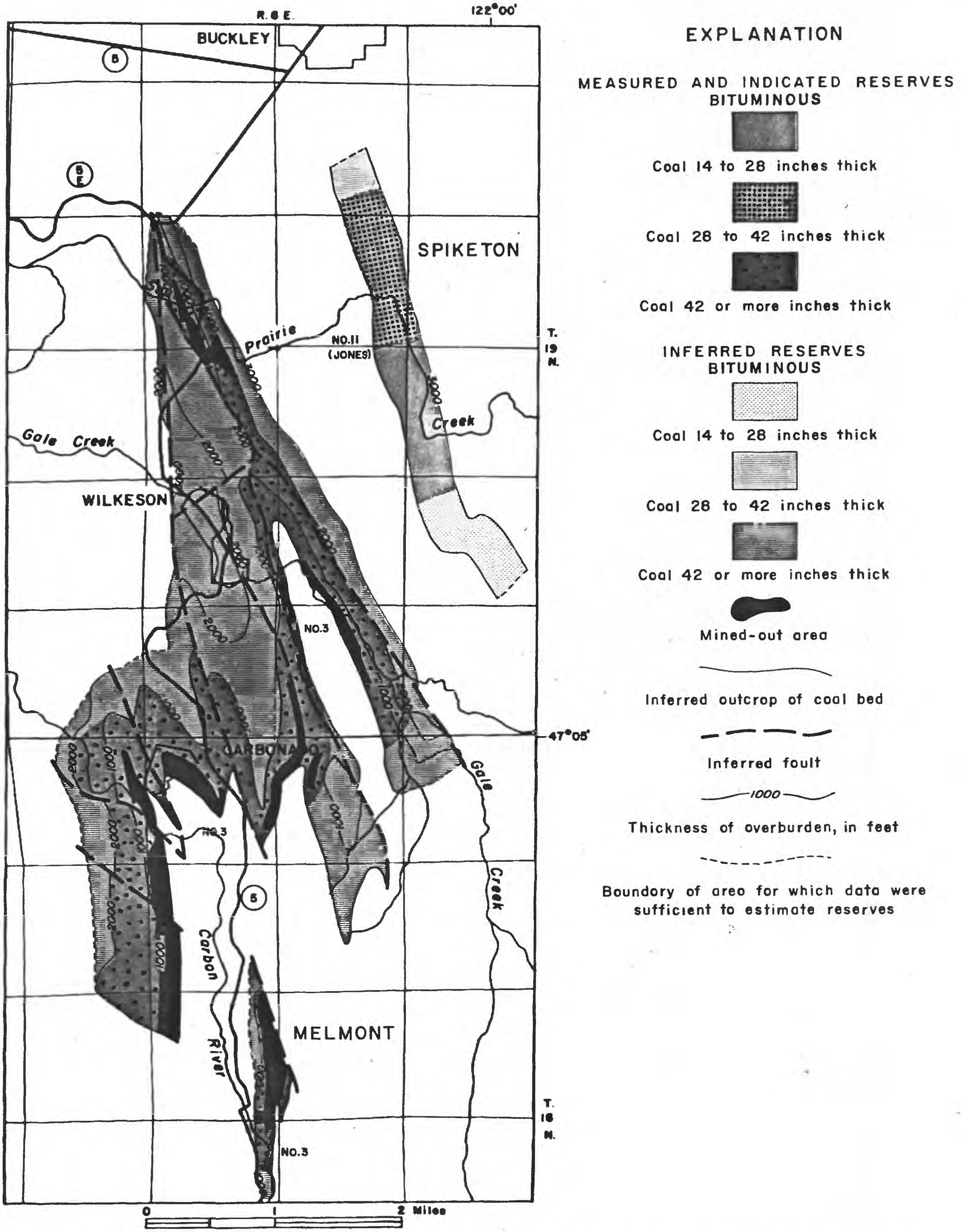

FIGURE 30.—GENERALIZED MAP OF THE NO. 3 BED OF MELMONT, NO. 3 BED OF WILKESON, AND NO. 11 (JONES) BED OF SPIKETON
(From Beikman and others, 1961, p. 73)

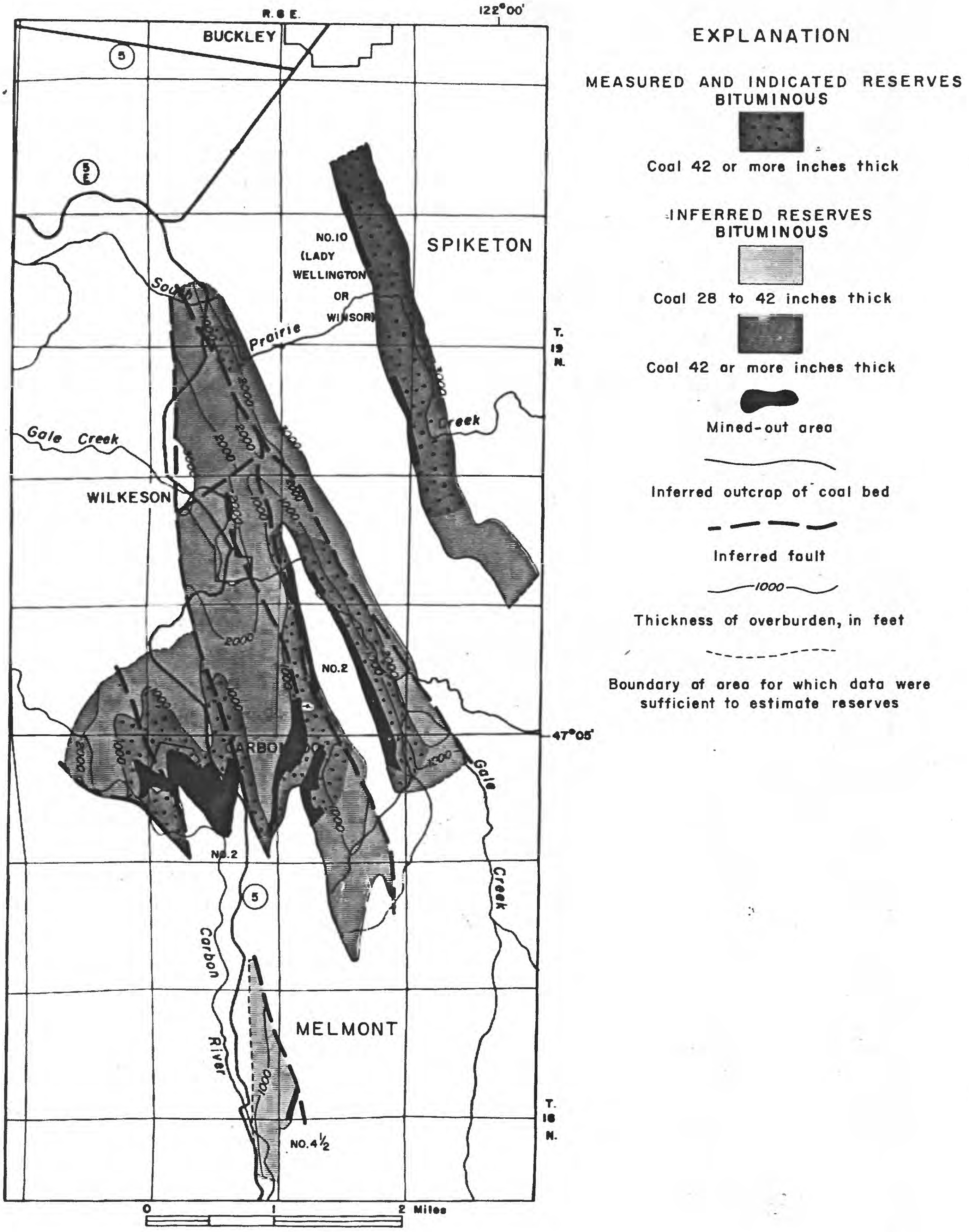

FIGURE 31.—GENERALIZED MAP OF THE NO. 4½ BED OF MELMONT, NO. 2 BED OF WILKESON, AND NO. 10 (LADY WELLINGTON OR WINSOR) BED OF SPIKETON
(From Beikman and others, 1961, p. 74)

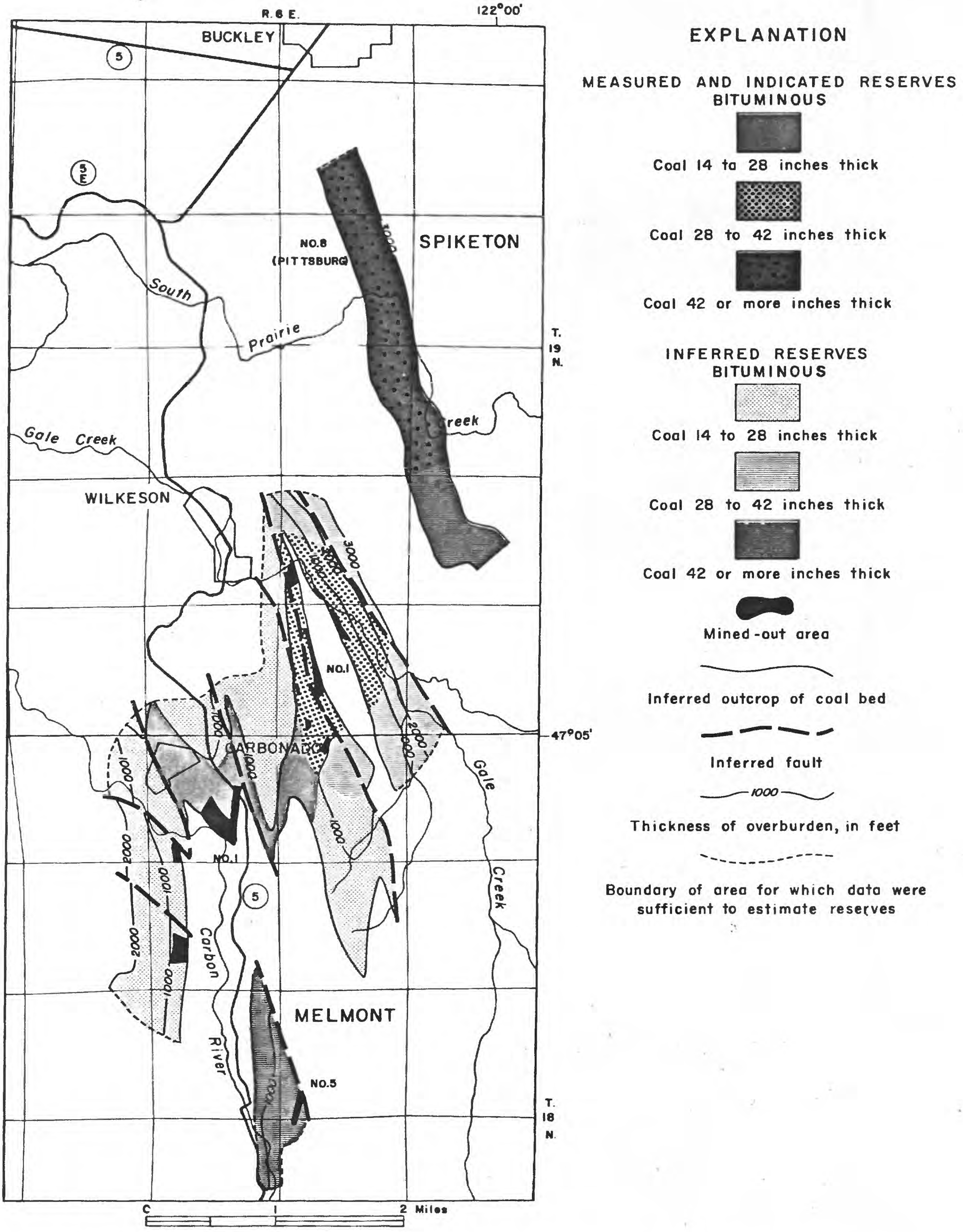

FIGURE 32.—GENERALIZED MAP OF THE NO. 5 BED OF MELMONT, NO. 1 BED OF WILKESON, AND NO. 8 (PITTSBURG) BED OF SPIKETON
(From Beikman and others, 1961, p. 75)

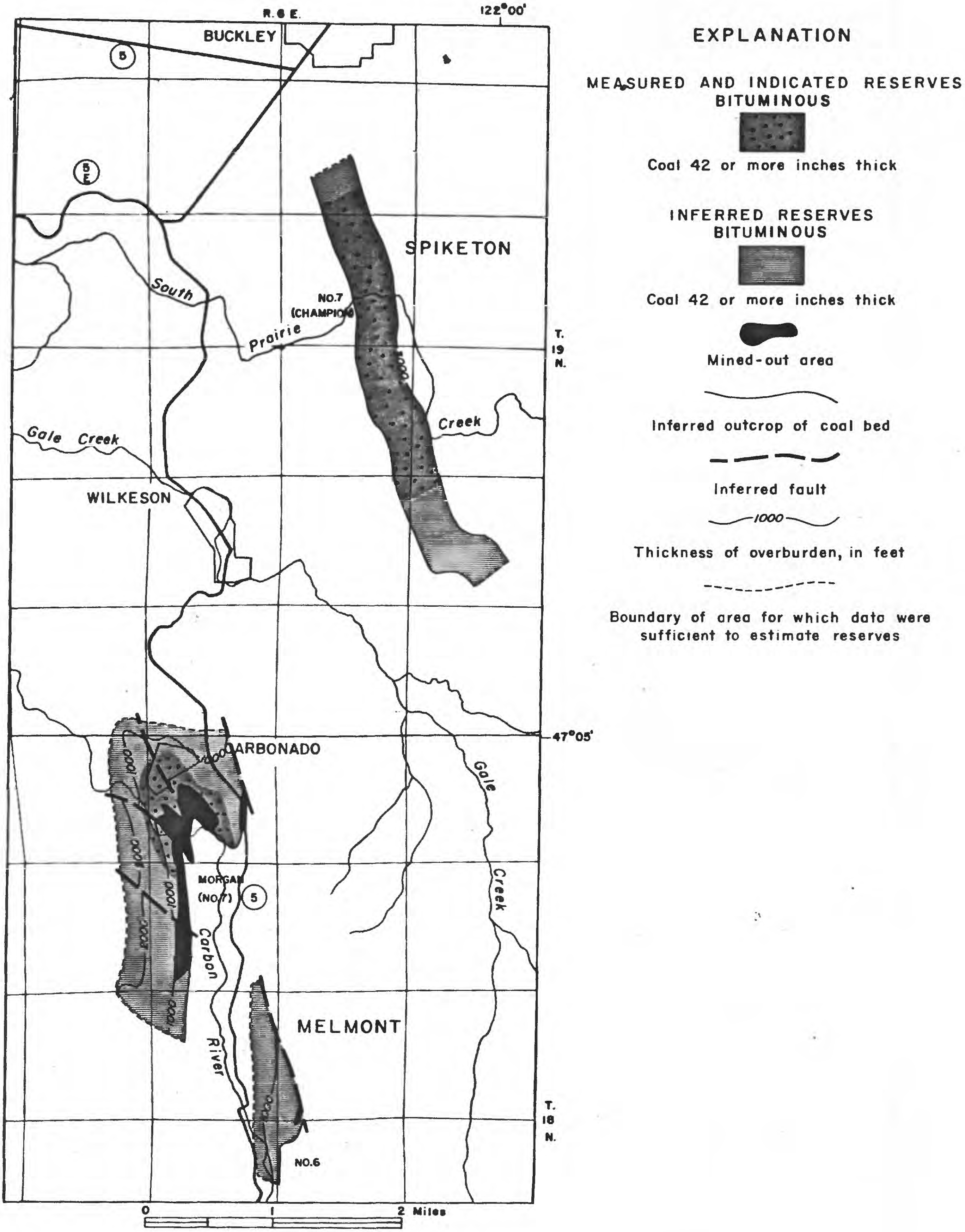

FIGURE 33.—GENERALIZED MAP OF THE NO. 6 BED OF MELMONT, MORGAN (NO. 7) BED OF CARBONADO, AND NO. 7 (CHAMPION) BED OF SPIKETON
(From Beikman and others, 1961, p. 76)

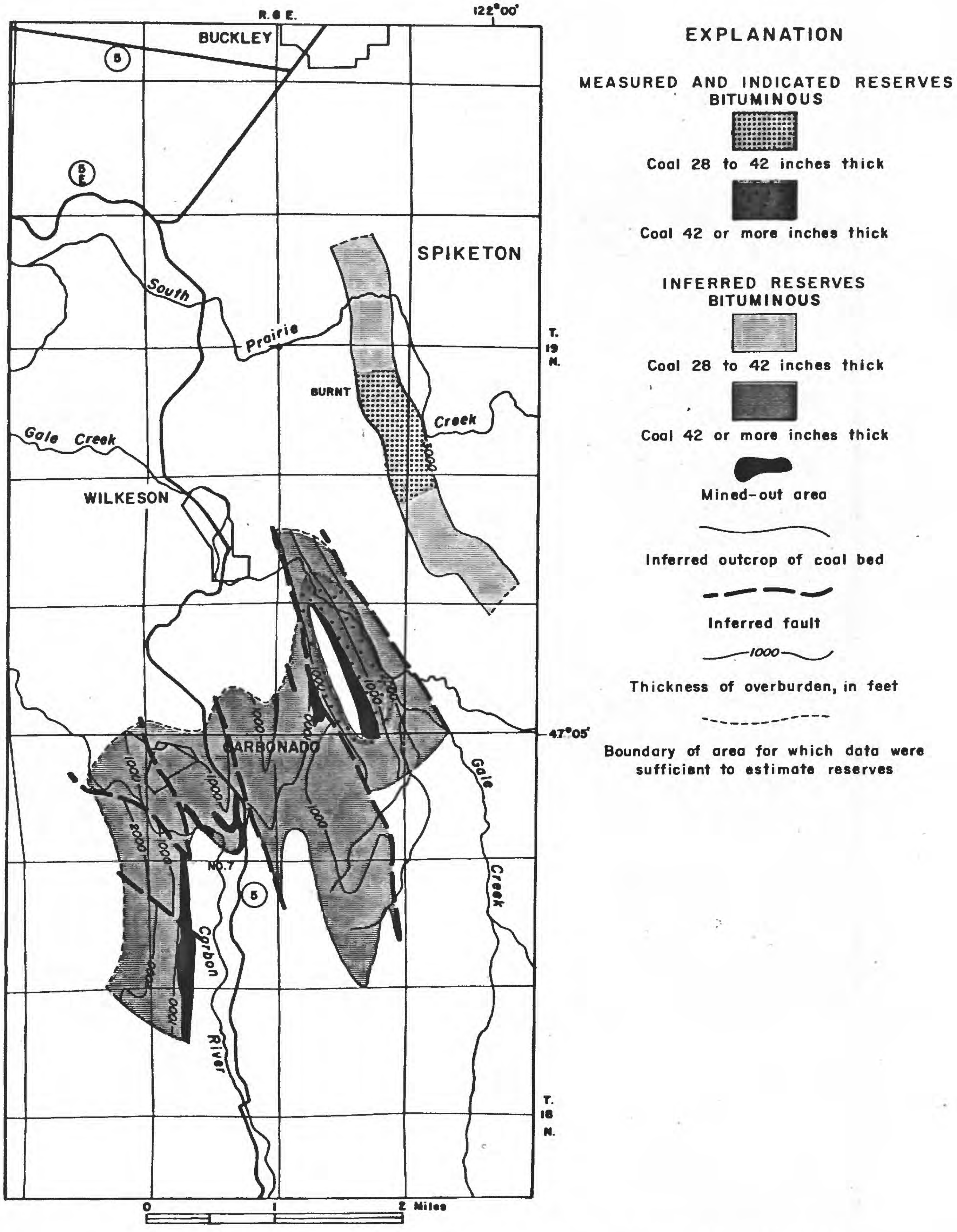

FIGURE 34.—GENERALIZED MAP OF THE NO. 7 BED OF WILKESON AND BURNT BED OF SPIKETON
(From Beikman and others, 1961, p. 77)

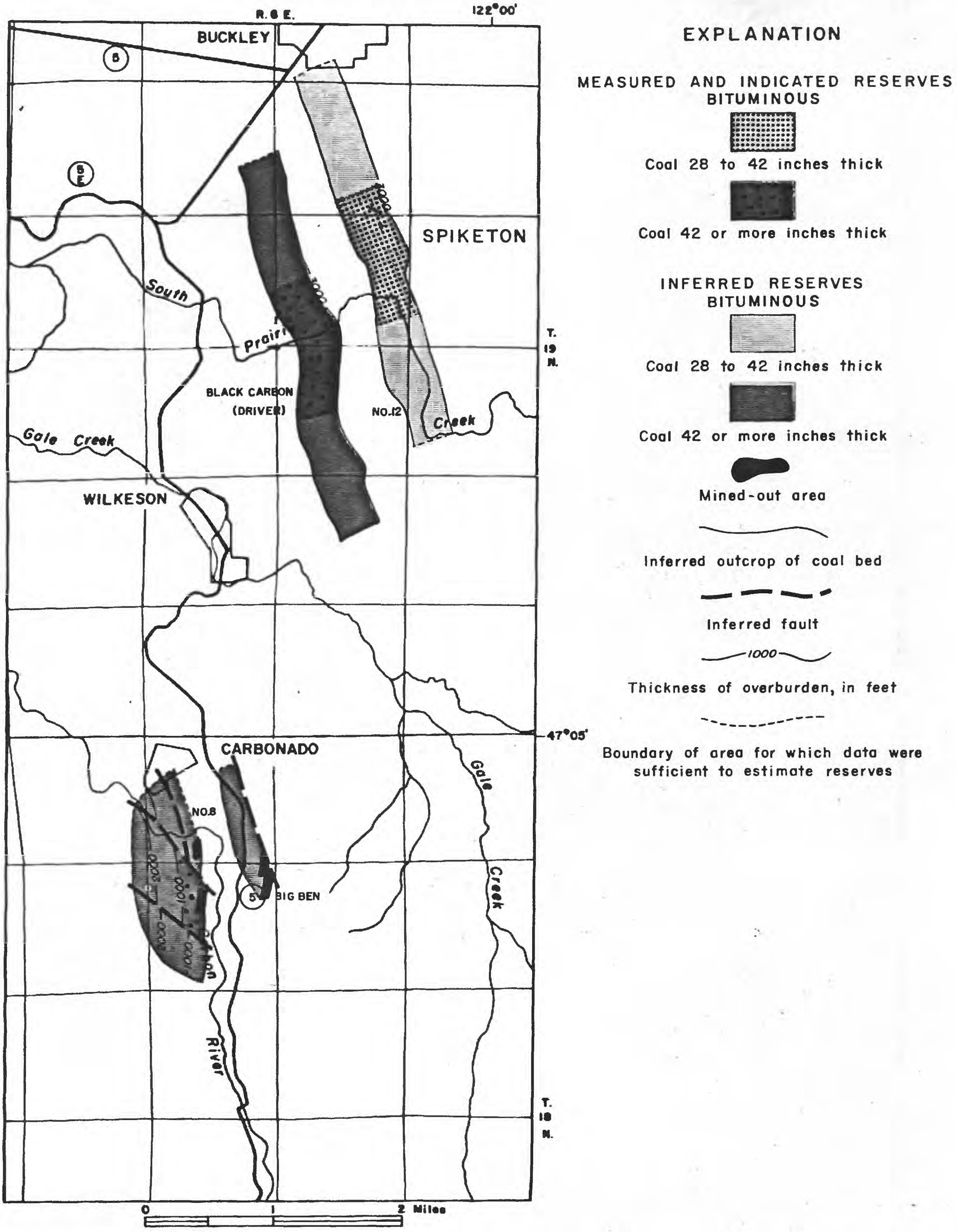

FIGURE 35.—GENERALIZED MAP OF THE NO. 8 AND BIG BEN BEDS OF CARBONADO AND THE BLACK CARBON (DRIVER) AND NO. 12 BEDS OF SPIKETON
(From Beikman and others, 1961, p. 78)

Table 11.—Estimated remaining reserves of coal in the Wilkeson-Carbonado coal field, Washington, as of January 1, 1960, by township and bed

(From Beikman and others, 1961, p. 81-82)

Coal bed	Overburden (in feet)	Reserves, in millions of short tons, in beds of thickness shown: Measured and indicated				Inferred				All categories			
		14 to 28 inches	28 to 42 inches	42 or more inches	Total	14 to 28 inches	28 to 42 inches	42 or more inches	Total	14 to 28 inches	28 to 42 inches	42 or more inches	Total
T. 18 N., R. 6 E.													
Wilkeson No. 5	0-1,000	-----	0.27	2.27	2.54	-----	0.25	0.07	0.32	-----	0.52	2.34	2.86
	1,000-2,000	-----	-----	.31	.31	-----	.01	1.19	1.20	-----	.01	1.50	1.51
Bed total		-----	0.27	2.58	2.85	-----	0.26	1.26	1.52	-----	0.53	2.84	4.37
Wilkeson No. 4	0-1,000	-----	-----	1.24	1.24	-----	2.21	0.34	2.55	-----	2.21	1.58	3.79
	1,000-2,000	-----	-----	.81	.81	-----	.07	1.23	1.30	-----	.07	2.04	2.11
Bed total		-----	-----	2.05	2.05	-----	2.28	1.57	3.85	-----	2.28	3.62	5.90
Carbonado No. 5	0-1,000	-----	-----	2.71	2.71	-----	-----	-----	-----	-----	-----	2.71	2.71
	1,000-2,000	-----	-----	-----	-----	-----	-----	2.58	2.58	-----	-----	2.58	2.58
Bed total		-----	-----	2.71	2.71	-----	-----	2.58	2.58	-----	-----	5.29	5.29
Wilkeson No. 3	0-1,000	-----	-----	3.52	3.52	-----	-----	5.05	5.05	-----	-----	8.57	8.57
	1,000-2,000	-----	-----	4.06	4.06	-----	-----	2.24	2.24	-----	-----	6.30	6.30
	2,000-3,000	-----	-----	.20	.20	-----	-----	1.97	1.97	-----	-----	2.17	2.17
Bed total		-----	-----	7.78	7.78	-----	-----	9.26	9.26	-----	-----	17.04	17.04
Wilkeson No. 2	0-1,000	-----	-----	5.22	5.22	-----	-----	3.44	3.44	-----	-----	8.66	8.66
	1,000-2,000	-----	-----	.34	.34	-----	-----	3.44	3.44	-----	-----	3.78	3.78
	2,000-3,000	-----	-----	-----	-----	-----	-----	.40	.40	-----	-----	.40	.40
Bed total		-----	-----	5.56	5.56	-----	-----	7.28	7.28	-----	-----	12.84	12.84
Wilkeson No. 1	0-1,000	1.58	0.05	-----	1.63	2.69	1.03	-----	3.72	4.27	1.08	-----	5.35
	1,000-2,000	-----	-----	-----	-----	2.47	.29	-----	2.76	2.47	.29	-----	2.76
	2,000-3,000	-----	-----	-----	-----	-----	.01	-----	.01	-----	.01	-----	.01
Bed total		1.58	0.05	-----	1.63	5.16	1.33	-----	6.49	6.74	1.38	-----	8.12
Morgan (No. 7)	0-1,000	-----	-----	1.98	1.98	-----	-----	2.22	2.22	-----	-----	4.20	4.20
	1,000-2,000	-----	-----	.22	.22	-----	-----	4.41	4.41	-----	-----	4.63	4.63
	2,000-3,000	-----	-----	-----	-----	-----	-----	2.29	2.29	-----	-----	2.29	2.29
Bed total		-----	-----	2.20	2.20	-----	-----	8.92	8.92	-----	-----	11.12	11.12
Wilkeson No. 7	0-1,000	-----	-----	0.07	0.07	-----	-----	14.05	14.05	-----	-----	14.12	14.12
	1,000-2,000	-----	-----	-----	-----	-----	-----	11.18	11.18	-----	-----	11.18	11.18
	2,000-3,000	-----	-----	-----	-----	-----	-----	.30	.30	-----	-----	.30	.30
Bed total		-----	-----	0.07	0.07	-----	-----	25.53	25.53	-----	-----	25.60	25.60
Carbonado No. 8	0-1,000	-----	-----	1.08	1.08	-----	-----	2.40	2.40	-----	-----	3.48	3.48
	1,000-2,000	-----	-----	-----	-----	-----	-----	2.99	2.99	-----	-----	2.99	2.99
	2,000-3,000	-----	-----	-----	-----	-----	-----	1.59	1.59	-----	-----	1.59	1.59
Bed total		-----	-----	1.08	1.08	-----	-----	6.98	6.98	-----	-----	8.06	8.06
Big Ben	0-1,000	-----	-----	-----	-----	-----	-----	1.92	1.92	-----	-----	1.92	1.92
Township total		1.58	0.32	24.03	25.93	5.16	3.87	65.30	74.33	6.74	4.19	89.33	100.26
T. 19 N., R 6 E.													
Wilkeson No. 5	0-1,000	-----	1.73	3.60	5.33	-----	0.73	4.15	4.88	-----	2.46	7.75	10.21
	1,000-2,000	-----	.95	-----	.95	-----	1.93	3.07	5.00	-----	2.88	3.07	5.95
	2,000-3,000	-----	-----	-----	-----	-----	.15	-----	.15	-----	.15	-----	.15
Bed total		-----	2.68	3.60	6.28	-----	2.81	7.22	10.03	-----	5.49	10.82	16.31
Wilkeson No. 4	0-1,000	-----	4.61	0.03	4.64	-----	2.29	1.86	4.15	-----	6.90	1.89	8.79
	1,000-2,000	-----	-----	-----	-----	-----	7.68	.61	8.29	-----	7.68	.61	8.29
	2,000-3,000	-----	-----	-----	-----	-----	.72	-----	.72	-----	.72	-----	.72
Bed total		-----	4.61	0.03	4.64	-----	10.69	2.47	13.16	-----	15.30	2.50	17.80
Carbonado No. 5	0-1,000	-----	-----	0.35	0.35	-----	-----	-----	-----	-----	-----	0.35	0.35
	1,000-2,000	-----	-----	-----	-----	-----	-----	0.58	0.58	-----	-----	.58	.58
Bed total		-----	-----	0.35	0.35	-----	-----	0.58	0.58	-----	-----	0.93	0.93
Wilkeson No. 3	0-1,000	-----	-----	8.99	8.99	-----	-----	0.46	0.46	-----	-----	9.45	9.45
	1,000-2,000	-----	-----	7.88	7.88	-----	-----	9.75	9.75	-----	-----	17.63	17.63
	2,000-3,000	-----	-----	-----	-----	-----	-----	10.81	10.81	-----	-----	10.81	10.81
Bed total		-----	-----	16.87	16.87	-----	-----	21.02	21.02	-----	-----	37.89	37.89
Wilkeson No. 2	0-1,000	-----	-----	5.41	5.41	-----	-----	0.80	0.80	-----	-----	6.21	6.21
	1,000-2,000	-----	-----	2.44	2.44	-----	-----	11.35	11.35	-----	-----	13.79	13.79
	2,000-3,000	-----	-----	.14	.14	-----	-----	8.19	8.19	-----	-----	8.33	8.33
Bed total		-----	-----	7.99	7.99	-----	-----	20.34	20.34	-----	-----	28.33	28.33
Wilkeson No. 1	0-1,000	0.15	1.79	-----	1.94	0.19	0.64	-----	0.83	0.34	2.43	-----	2.77
	1,000-2,000	-----	.98	-----	.98	1.72	.34	-----	2.06	1.72	1.32	-----	3.04
	2,000-3,000	-----	.16	-----	.16	-----	.90	-----	.90	-----	1.06	-----	1.06
Bed total		0.15	2.93	-----	3.08	1.91	1.88	-----	3.79	2.06	4.81	-----	6.87
Morgan (No. 7)	0-1,000	-----	-----	-----	-----	-----	-----	0.01	0.01	-----	-----	0.01	0.01
	1,000-2,000	-----	-----	-----	-----	-----	-----	.64	.64	-----	-----	.64	.64
Bed total		-----	-----	-----	-----	-----	-----	0.65	0.65	-----	-----	0.65	0.65

Table 11.—Estimated remaining reserves of coal in the Wilkeson-Carbonado coal field, Washington, as of January 1, 1960, by township and bed—Continued

Coal bed	Overburden (in feet)	Reserves, in millions of short tons, in beds of thickness shown — Measured and indicated: 14 to 28 inches	28 to 42 inches	42 or more inches	Total	Inferred: 14 to 28 inches	28 to 42 inches	42 or more inches	Total	All categories: 14 to 28 inches	28 to 42 inches	42 or more inches	Total
						T. 19 N., R. 6 E.—continued							
Wilkeson No. 7	0-1,000	-----	-----	3.03	3.03	-----	-----	1.31	1.31	-----	-----	4.34	4.34
	1,000-2,000	-----	-----	2.14	2.14	-----	-----	3.90	3.90	-----	-----	6.04	6.04
	2,000-3,000	-----	-----	-----	-----	-----	-----	2.65	2.65	-----	-----	2.65	2.65
Bed total		-----	-----	5.17	5.17	-----	-----	7.86	7.86	-----	-----	13.03	13.03
Township total		0.15	10.22	34.01	44.38	1.91	15.38	60.14	77.43	2.06	25.60	94.15	121.81
Grand total		1.73	10.54	58.04	70.31	7.07	19.25	125.44	151.76	8.80	29.79	183.48	222.07

Table 12.-- Estimated remaining reserves of coal in the Spiketon area, Washington, as of January 1, 1960, by township and bed

(From Beikman and others, 1961, p. 82)

Coal bed	Overburden (in feet)	Reserves, in millions of short tons, in beds of thickness shown — Measured and indicated: 14 to 28 inches	28 to 42 inches	42 or more inches	Total	Inferred: 14 to 28 inches	28 to 42 inches	42 or more inches	Total	All categories: 14 to 28 inches	28 to 42 inches	42 or more inches	Total
						T. 19 N., R. 6 E.							
Crocker	0-1,000	0.58	------	------	0.58	1.12	------	------	1.12	1.70	------	------	1.70
	1,000-2,000	.58	------	------	.58	1.12	------	------	1.12	1.70	------	------	1.70
	2,000-3,000	.58	------	------	.58	1.12	------	------	1.12	1.70	------	------	1.70
Bed total		1.74	------	------	1.74	3.36	------	------	3.36	5.10	------	------	5.10
No. 12	0-1,000	------	0.93	------	0.93	------	1.74	------	1.74	------	2.67	------	2.67
	1,000-2,000	------	.93	------	.93	------	1.74	------	1.74	------	2.67	------	2.67
	2,000-3,000	------	.93	------	.93	------	1.74	------	1.74	------	2.67	------	2.67
Bed total		------	2.79	------	2.79	------	5.22	------	5.22	------	8.01	------	8.01
No. 11	0-1,000	0.59	0.88	------	1.47	0.39	0.26	------	0.65	0.98	1.14	------	2.12
	1,000-2,000	.59	.88	------	1.47	.39	.79	------	1.18	.98	1.67	------	2.65
	2,000-3,000	.59	.88	------	1.47	.39	.79	------	1.18	.98	1.67	------	2.65
Bed total		1.77	2.64	------	4.41	1.17	1.84	------	3.01	2.94	4.48	------	7.42
No. 10	0-1,000	------	------	2.77	2.77	------	------	0.74	0.74	------	------	3.51	3.51
	1,000-2,000	------	------	3.02	3.02	------	------	1.87	1.87	------	------	4.89	4.89
	2,000-3,000	------	------	3.02	3.02	------	------	1.87	1.87	------	------	4.89	4.89
Bed total		------	------	8.81	8.81	------	------	4.48	4.48	------	------	13.29	13.29
No. 8	0-1,000	------	------	2.88	2.88	------	------	1.00	1.00	------	------	3.88	3.88
	1,000-2,000	------	------	3.07	3.07	------	------	2.12	2.12	------	------	5.19	5.19
	2,000-3,000	------	------	3.07	3.07	------	------	2.12	2.12	------	------	5.19	5.19
Bed total		------	------	9.02	9.02	------	------	5.24	5.24	------	------	14.26	14.26
Snell	0-1,000	0.37	------	------	0.37	0.24	------	------	0.24	0.61	------	------	0.61
	1,000-2,000	.37	------	------	.37	.24	------	------	.24	.61	------	------	.61
	2,000-3,000	.37	------	------	.37	.24	------	------	.24	.61	------	------	.61
Bed total		1.11	------	------	1.11	0.72	------	------	0.72	1.83	------	------	1.83
No. 7	0-1,000	------	------	2.67	2.67	------	------	1.22	1.22	------	------	3.89	3.89
	1,000-2,000	------	------	2.67	2.67	------	------	2.03	2.03	------	------	4.70	4.70
	2,000-3,000	------	------	2.67	2.67	------	------	2.03	2.03	------	------	4.70	4.70
Bed total		------	------	8.01	8.01	------	------	5.28	5.28	------	------	13.29	13.29
Burnt	0-1,000	------	0.76	------	0.76	------	1.60	------	1.60	------	2.36	------	2.36
	1,000-2,000	------	.76	------	.76	------	1.60	------	1.60	------	2.36	------	2.36
	2,000-3,000	------	.76	------	.76	------	1.60	------	1.60	------	2.36	------	2.36
Bed total		------	2.28	------	2.28	------	4.80	------	4.80	------	7.08	------	7.08
No. 6	0-1,000	0.36	0.47	1.17	2.00	0.42	------	0.23	0.65	0.78	0.47	1.40	2.65
	1,000-2,000	.36	.47	1.17	2.00	.42	------	1.09	1.51	.78	.47	2.26	3.51
	2,000-3,000	.36	.47	1.17	2.00	.42	------	1.09	1.51	.78	.47	2.26	3.51
Bed total		1.08	1.41	3.51	6.00	1.26	------	2.41	3.67	2.34	1.41	5.92	9.67
Black Carbon	0-1,000	------	------	1.18	1.18	------	------	1.49	1.49	------	------	2.67	2.67
	1,000-2,000	------	------	1.18	1.18	------	------	1.93	1.93	------	------	3.11	3.11
	2,000-3,000	------	------	1.18	1.18	------	------	1.93	1.93	------	------	3.11	3.11
Bed total		------	------	3.54	3.54	------	------	5.35	5.35	------	------	8.89	8.89
Grand total		5.70	9.12	32.89	47.71	6.51	11.86	22.76	41.13	12.21	20.98	55.65	88.84

Table 13.—Estimated remaining reserves of coal in the Melmont area, Washington, as of January 1, 1960, by township and bed

(From Beikman and others, 1961, p. 83)

Coal bed	Overburden (in feet)	Reserves, in millions of short tons, in beds of thickness shown											
		Measured and indicated				Inferred				All categories			
		14 to 28 inches	28 to 42 inches	42 or more inches	Total	14 to 28 inches	28 to 42 inches	42 or more inches	Total	14 to 28 inches	28 to 42 inches	42 or more inches	Total
T. 18 N., R. 6 E.													
No. 1	0-1,000	------	------	0.29	0.29	------	------	0.47	0.47	------	------	0.76	0.76
No. 2	0-1,000	------	------	1.25	1.25	------	------	2.37	2.37	------	------	3.62	3.62
	1,000-2,000	------	------	------	------	------	------	.25	.25	------	------	.25	.25
Bed total		------	------	1.25	1.25	------	------	2.62	2.62	------	------	3.87	3.87
No. 2½	0-1,000	------	------	------	------	------	------	1.28	1.28	------	------	1.28	1.28
No. 3	0-1,000	------	------	0.04	0.04	------	------	0.29	0.29	------	------	0.33	0.33
	1,000-2,000	------	------	------	------	------	------	.69	.69	------	------	.69	.69
Bed total		------	------	0.04	0.04	------	------	0.98	0.98	------	------	1.02	1.02
No. 4½	0-1,000	------	------	------	------	------	0.99	------	0.99	------	0.99	------	0.99
	1,000-2,000	------	------	------	------	------	.65	------	.65	------	.65	------	.65
Bed total		------	------	------	------	------	1.64	------	1.64	------	1.64	------	1.64
No. 5	0-1,000	------	------	------	------	------	------	2.32	2.32	------	------	2.32	2.32
	1,000-2,000	------	------	------	------	------	------	1.69	1.69	------	------	1.69	1.69
Bed total		------	------	------	------	------	------	4.01	4.01	------	------	4.01	4.01
No. 6	0-1,000	------	------	------	------	------	------	1.73	1.73	------	------	1.73	1.73
	1,000-2,000	------	------	------	------	------	------	2.18	2.18	------	------	2.18	2.18
Bed total		------	------	------	------	------	------	3.91	3.91	------	------	3.91	3.91
Grand total		------	------	1.58	1.58	------	1.64	13.27	14.91	------	1.64	14.85	16.49

Fiarfax-Montezuma area

Six or more coal beds have been opened or mined to varying extents in the Fairfax-Montezuma area, however, the total number of beds present is unknown owing to the complexities of the structure and lack of data. The reserve bases were estimated for several coal beds on which thickness data were available but these estimates cover limited areas of coal occurrence that were apparent from the mine workings (Beikman and others, 1961, p. 79). The maximum area for which the reserve base has been estimated is shown on figure 36. Due to the lack of correlation between coal beds and the restricted area for which reserve estimates were prepared, individual maps of the various coals are not presented.

The reserve base of coal in the Fairfax-Montezuma area is estimated to total 21 million tons, of which about 60 percent is classed as measured and indicated (Beikman and others, 1911, p. 83). The reserve base figures by township and bed are shwon in table 14.

Ashford area

Although numerous coal beds are believed to occur near Ashford, the reserve base has been estimated for only the one coal bed that has been mined in the area. This bed, the Nisqually, commonly consists of two benches and is more than 10 feet thick in places. The reserve base of the Nisqually coal bed is estimated to total 13 million tons, all classified as inferred (Beikman and others, 1961, p. 83). The reserve base figures by township and bed are shown in table 15.

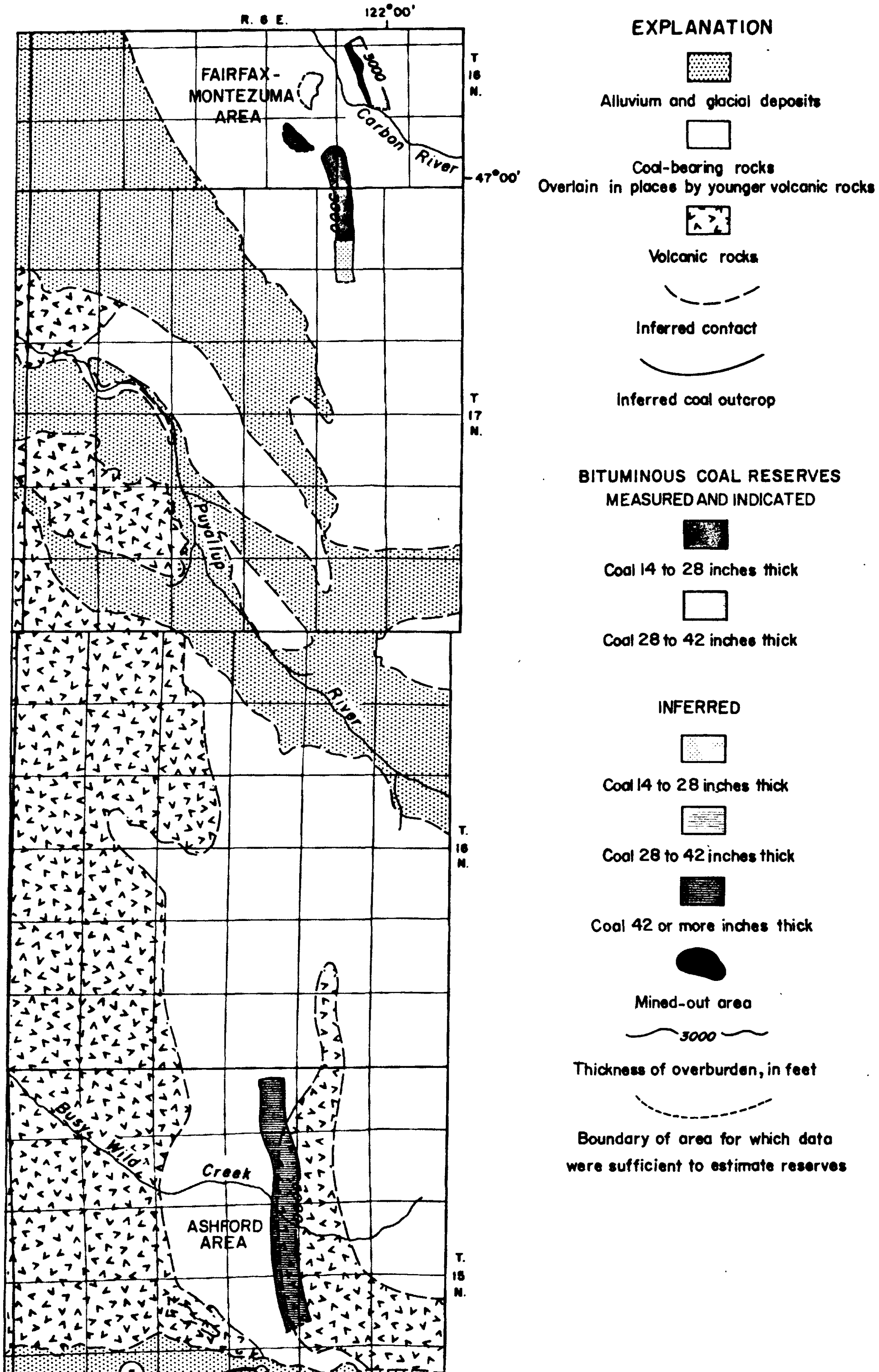

FIGURE 36.—MAP OF THE FAIRFAX-MONTEZUMA AND ASHFORD COAL AREAS
(From Beikman and others, 1961, p. 80)

Table 14 —Estimated remaining reserves of coal in the Fairfax-Montezuma area, Washington, as of January 1, 1960, by township and bed

(From Beikman and others, 1961, p. 84-85)

Coal bed	Overburden (in feet)	Reserves, in millions of short tons, in beds of thickness shown: Measured and indicated: 14 to 28 inches	28 to 42 inches	42 or more inches	Total	Inferred: 14 to 28 inches	28 to 42 inches	42 or more inches	Total	All categories: 14 to 28 inches	28 to 42 inches	42 or more inches	Total
						T. 17 N., R. 6 E.							
No. 1	0-1,000	0.08	-----	-----	0.08	0.19	-----	-----	0.19	0.27	-----	-----	0.27
	1,000-2,000	.08	-----	-----	.08	.19	-----	-----	.19	.27	-----	-----	.27
	2,000-3,000	.08	-----	-----	.08	.19	-----	-----	.19	.27	-----	-----	.27
Bed total		0.24	-----	-----	0.24	0.57	-----	-----	0.57	0.81	-----	-----	0.81
No. 2	0-1,000	0.15	-----	-----	0.15	0.25	-----	-----	0.25	0.40	-----	-----	0.40
	1,000-2,000	.15	-----	-----	.15	.25	-----	-----	.25	.40	-----	-----	.40
	2,000-3,000	.15	-----	-----	.15	.25	-----	-----	.25	.40	-----	-----	.40
Bed total		0.45	-----	-----	0.45	0.75	-----	-----	0.75	1.20	-----	-----	1.20
No. 3	0-1,000	0.10	0.36	-----	0.46	-----	0.34	-----	0.34	0.10	0.70	-----	0.80
	1,000-2,000	.10	.36	-----	.46	-----	.34	-----	.34	.10	.70	-----	.80
	2,000-3,000	.10	.36	-----	.46	-----	.34	-----	.34	.10	.70	-----	.80
Bed total		0.30	1.08	-----	1.38	-----	1.02	-----	1.02	0.30	2.10	-----	2.40
No. 4	0-1,000	-----	0.40	-----	0.40	-----	0.17	-----	0.17	-----	0.57	-----	0.57
	1,000-2,000	-----	.40	-----	.40	-----	.17	-----	.17	-----	.57	-----	.57
	2,000-3,000	-----	.40	-----	.40	-----	.17	-----	.17	-----	.57	-----	.57
Bed total		-----	1.20	-----	1.20	-----	0.51	-----	0.51	-----	1.71	-----	1.71
No. 5	0-1,000	0.05	0.38	-----	0.43	-----	0.29	-----	0.29	0.05	0.67	-----	0.72
	1,000-2,000	.05	.38	-----	.43	-----	.29	-----	.29	.05	.67	-----	.72
	2,000-3,000	.05	.38	-----	.43	-----	.29	-----	.29	.05	.67	-----	.72
Bed total		0.15	1.14	-----	1.29	-----	0.87	-----	0.87	0.15	2.01	-----	2.16
No. 6	0-1,000	0.44	-----	-----	0.44	0.27	-----	-----	0.27	0.71	-----	-----	0.71
	1,000-2,000	.44	-----	-----	.44	.27	-----	-----	.27	.71	-----	-----	.71
	2,000-3,000	.44	-----	-----	.44	.27	-----	-----	.27	.71	-----	-----	.71
Bed total		1.32	-----	-----	1.32	0.81	-----	-----	0.81	2.13	-----	-----	2.13
Township total		2.46	3.42	-----	5.88	2.13	2.40	-----	4.53	4.59	5.82	-----	10.41
						T. 18 N., R. 6 E. (North of Carbon River)							
Blacksmith	0-1,000	0.37	-----	-----	0.37	-----	-----	-----	-----	0.37	-----	-----	0.37
	1,000-2,000	.37	-----	-----	.37	-----	-----	-----	-----	.37	-----	-----	.37
	2,000-3,000	.37	-----	-----	.37	-----	-----	-----	-----	.37	-----	-----	.37
Bed total		1.11	-----	-----	1.11	-----	-----	-----	-----	1.11	-----	-----	1.11
No. 2	0-1,000	0.20	-----	-----	0.20	-----	-----	-----	-----	0.20	-----	-----	0.20
	1,000-2,000	.20	-----	-----	.20	-----	-----	-----	-----	.20	-----	-----	.20
	2,000-3,000	.20	-----	-----	.20	-----	-----	-----	-----	.20	-----	-----	.20
Bed total		0.60	-----	-----	0.60	-----	-----	-----	-----	0.60	-----	-----	0.60
McNeill	0-1,000	-----	0.63	-----	0.63	-----	-----	-----	-----	-----	0.63	-----	0.63
	1,000-2,000	-----	.82	-----	.82	-----	-----	-----	-----	-----	.82	-----	.82
	2,000-3,000	-----	.82	-----	.82	-----	-----	-----	-----	-----	.82	-----	.82
Bed total		-----	2.27	-----	2.27	-----	-----	-----	-----	-----	2.27	-----	2.27
						(South of Carbon River)							
No. 1	0-1,000	0.15	-----	-----	0.15	-----	-----	-----	-----	0.15	-----	-----	0.15
	1,000-2,000	.15	-----	-----	.15	-----	-----	-----	-----	.15	-----	-----	.15
	2,000-3,000	.15	-----	-----	.15	-----	-----	-----	-----	.15	-----	-----	.15
Bed total		0.45	-----	-----	0.45	-----	-----	-----	-----	0.45	-----	-----	0.45
No. 2	0-1,000	0.21	-----	-----	0.21	-----	-----	-----	-----	0.21	-----	-----	0.21
	1,000-2,000	.21	-----	-----	.21	-----	-----	-----	-----	.21	-----	-----	.21
	2,000-3,000	.21	-----	-----	.21	-----	-----	-----	-----	.21	-----	-----	.21
Bed total		0.63	-----	-----	0.63	-----	-----	-----	-----	0.63	-----	-----	0.63
No. 3	0-1,000	0.21	-----	-----	0.21	0.07	-----	-----	0.07	0.28	-----	-----	0.28
	1,000-2,000	.21	-----	-----	.21	.07	-----	-----	.07	.28	-----	-----	.28
	2,000-3,000	.21	-----	-----	.21	.07	-----	-----	.07	.28	-----	-----	.28
Bed total		0.63	-----	-----	0.63	0.21	-----	-----	0.21	0.84	-----	-----	0.84
No. 4	0-1,000	0.09	0.05	-----	0.14	0.04	-----	-----	0.04	0.13	0.05	-----	0.18
	1,000-2,000	.09	.05	-----	.14	.04	-----	-----	.04	.13	.05	-----	.18
	2,000-3,000	.09	.05	-----	.14	.04	-----	-----	.04	.13	.05	-----	.18
Bed total		0.27	0.15	-----	0.42	0.12	-----	-----	0.12	0.39	0.15	-----	0.54
No. 5	0-1,000	0.13	-----	-----	0.13	0.08	-----	-----	0.08	0.21	-----	-----	0.21
	1,000-2,000	.13	-----	-----	.13	.08	-----	-----	.08	.21	-----	-----	.21
	2,000-3,000	.13	-----	-----	.13	.08	-----	-----	.08	.21	-----	-----	.21
Bed total		0.39	-----	-----	0.39	0.24	-----	-----	0.24	0.63	-----	-----	0.63

Table 14.—Estimated remaining reserves of coal in the Fairfax-Montezuma area, Washington, as of January 1, 1960, by township and bed—Continued

Coal bed	Overburden (in feet)	Reserves, in millions of short tons, in beds of thickness shown											
		Measured and indicated				Inferred				All categories			
		14 to 28 inches	28 to 42 inches	42 or more inches	Total	14 to 28 inches	28 to 42 inches	42 or more inches	Total	14 to 28 inches	28 to 42 inches	42 or more inches	Total
					T. 18 N., R. 6 E. (South of Carbon River)—continued								
No. 6	0-1,000	0.23	-----	-----	0.23	0.11	-----	-----	0.11	0.34	-----	-----	0.34
	1,000-2,000	.23	-----	-----	.23	.11	-----	-----	.11	.34	-----	-----	.34
	2,000-3,000	.23	-----	-----	.23	.11	-----	-----	.11	.34	-----	-----	.34
Bed total		0.69	-----	-----	0.69	0.33	-----	-----	0.33	1.02	-----	-----	1.02
Unnamed	0-1,000	-----	-----	-----	-----	-----	0.31	-----	0.31	-----	0.31	-----	0.31
	1,000-2,000	-----	-----	-----	-----	-----	.31	-----	.31	-----	.31	-----	.31
	2,000-3,000	-----	-----	-----	-----	-----	.31	-----	.31	-----	.31	-----	.31
Bed total		-----	-----	-----	-----	-----	0.93	-----	0.93	-----	0.93	-----	0.93
Unnamed	0-1,000	-----	-----	-----	-----	-----	0.24	-----	0.24	-----	0.24	-----	0.24
	1,000-2,000	-----	-----	-----	-----	-----	.24	-----	.24	-----	.24	-----	.24
	2,000-3,000	-----	-----	-----	-----	-----	.24	-----	.24	-----	.24	-----	.24
Bed total		-----	-----	-----	-----	-----	0.72	-----	0.72	-----	0.72	-----	0.72
Unnamed	0-1,000	-----	-----	-----	-----	-----	-----	0.33	0.33	-----	-----	0.33	0.33
	1,000-2,000	-----	-----	-----	-----	-----	-----	.33	.33	-----	-----	.33	.33
	2,000-3,000	-----	-----	-----	-----	-----	-----	.33	.33	-----	-----	.33	.33
Bed total		-----	-----	-----	-----	-----	-----	0.99	0.99	-----	-----	0.99	0.99
Township total		4.77	2.42	-----	7.19	0.90	1.65	0.99	3.54	5.67	4.07	0.99	10.73
Grand total		7.23	5.84	-----	13.07	3.03	4.05	0.99	8.07	10.26	9.89	0.99	21.14

Table 15.—Estimated remaining reserves of coal in the Ashford area, Washington, as of January 1, 1960, by township and bed

Coal bed	Overburden (in feet)	Reserves, in millions of short tons, in beds of thickness shown											
		Measured and indicated				Inferred				All categories			
		14 to 28 inches	28 to 42 inches	42 or more inches	Total	14 to 28 inches	28 to 42 inches	42 or more inches	Total	14 to 28 inches	28 to 42 inches	42 or more inches	Total
					T. 15 N., R. 6 E.								
Nisqually	0-1,000	-----	-----	-----	-----	-----	-----	4.47	4.47	-----	-----	4.47	4.47
	1,000-2,000	-----	-----	-----	-----	-----	-----	4.47	4.47	-----	-----	4.47	4.47
	2,000-3,000	-----	-----	-----	-----	-----	-----	4.47	4.47	-----	-----	4.47	4.47
Bed total		-----	-----	-----	-----	-----	-----	13.41	13.41	-----	-----	13.41	13.41
Township total		-----	-----	-----	-----	-----	-----	13.41	13.41	-----	-----	13.41	13.41

(From Beikman and others, 1961, p. 85)

TABLE 16.--Summary of coal resources, Wilkeson-Carbonado coal field, in millions of short tons (data from Beikman and others, 1961)

Area	Beds thicker than 42 inches			Beds thinner than 42 inches			Total all categories
	Measured and indicated	Inferred	Total	Measured and indicated	Inferred	Total	
Wilkeson-Carbonado	58.04	125.44	183.48	12.27	26.32	38.59	222.07
Spiketon	32.89	22.76	55.65	14.82	18.37	33.19	88.84
Melmont	1.58	13.27	14.85	-----	1.64	1.64	16.49
Fairfax-Montezuma	-----	0.99	0.99	13.07	7.08	20.15	21.14
Grand total	92.51	162.46	254.97	40.16	53.41	93.57	348.54

Possible additional reserves

Due to the lack of exposures in the Wilkeson-Carbonado coal field, knowledge of the coal-bearing sequence is confined largely to areas of extensive mining and little is known about the continuity and thickness of coal beds in the intervening areas. Consequently, the estimates of the coal reserve base included in this report cover areas of intensive mining where the data were sufficient to estimate the reserve base. Because of the scarcity of specific information, the coal reserve base could be estimated for only 30-50 percent of the known coal bearing area within the coal field, and much of the area for which the reserve base was estimated contains additional coal in beds of unknown thickness and extent. Beikman, Gower, and Dana (1961, p. 110), in the preparation of the estimates, indicated that the estimates "---are minimum estimates and that they will be increased in the future as additional information is acquired through detailed geologic data".

Possible other large areas of coal-bearing rocks are concealed beneath a mantle of glacial drift or alluvium. Figure 37 shows the known and possible areas of coal-bearing rocks in the state of Washington, and the area for which the coal reserve base has been estimated. As indicated on figure 37, there are considerable areas of known or possible coal-bearing rocks for which the reserve base was not estimated because specific information about the occurrence, quality, and thickness of the coal beds is lacking. When such detailed information becomes available, the estimated reserve base in the Wilkeson-Carbonado coal field will be substantially increased.

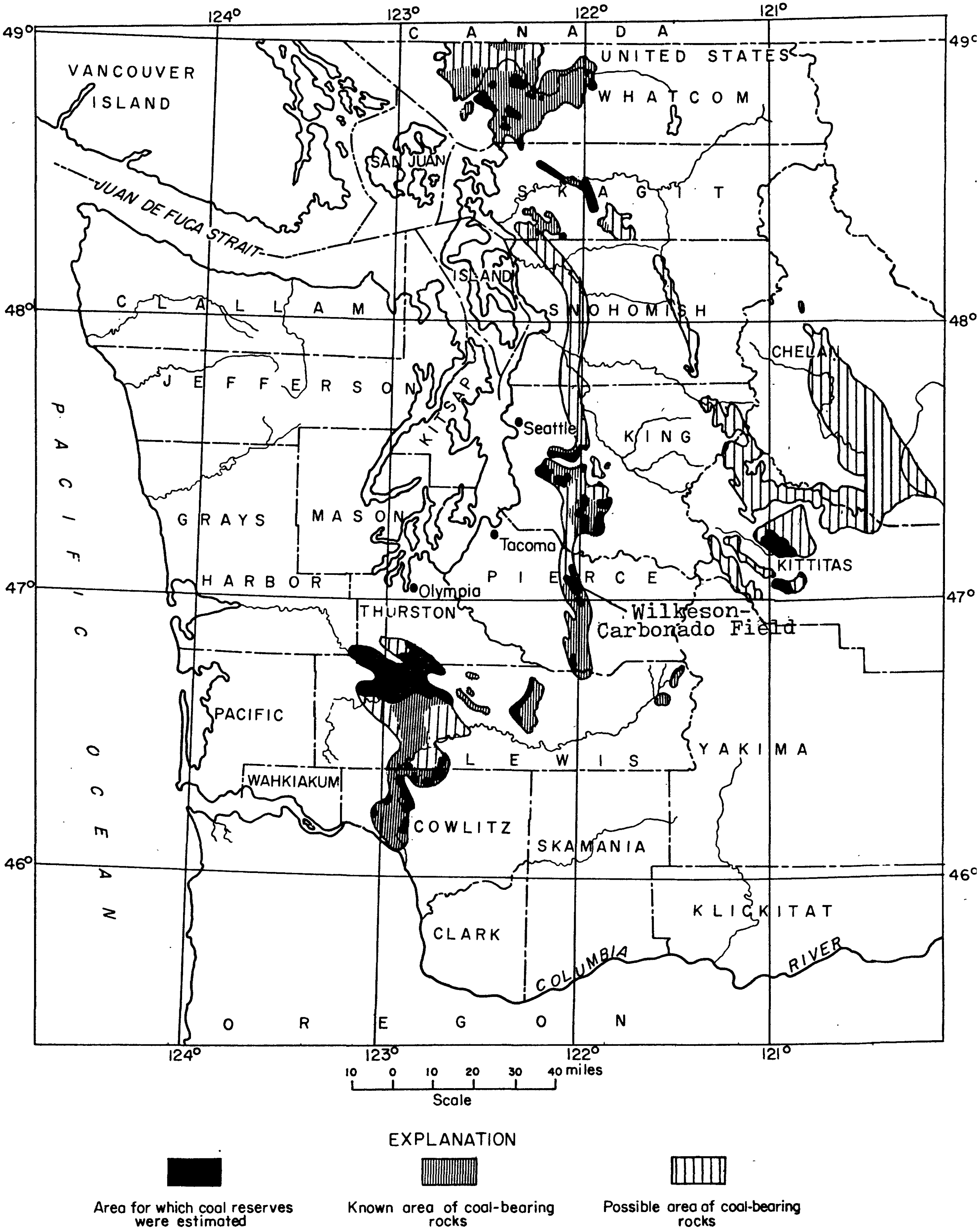

FIGURE 37.—INDEX MAP OF WASHINGTON SHOWING KNOWN AND POSSIBLE AREAS OF COAL-BEARING ROCKS (From Beikman and others, 1961, p. 111)

Coal Production

About 21,200,000 tons of coal have been produced in the Wilkeson-Carbonado coal field since mining began along in Gale Creek in 1874. Coal production reached a maximum of 832,272 tons in 1913, and declined thereafter. In 1959 the total annual production in the coal field was less than 1,000 tons (Beikman and others, 1961, p. 63). There are no operating mines in the coal field at this time (1977).

All but about 1,000 tons of the total coal produced in Pierce County, Washington have been mined in the Wilkeson-Carbonado field. Total production in the Wilkeson-Carbonado area since 1892 has exceeded 18.6 million tons, which is nearly 90 percent of the total production from Pierce County. Three mines accounted for nearly 18 million tons; these were the Carbonado mine originally operated by the Carbon Hill Coal Company and later by the Pacific Coast Coal Company, the Burnett mine of the Pacific Coast Coal Company, and the Wilkeson mine of the Wilkeson Coal and Coke Company (U.S. Bonneville Power Administration, 1963).

About a million tons of coal was produced in the Spiketon area from the early 1890's to 1930. This is about 4 percent of the total Pierce County coal production. About 900,000 tons was produced in the Melmont area between 1902 and 1918, which is slightly less than 4 percent of the total Pierce County production. About 700,000 tons or slightly less than 3 percent of the total Pierce County coal production came from the Fairfax-Montezuma area (Beikman and others, 1961).

Production of coal in Pierce County by 5-year intervals covering the period 1885 to 1959 is summarized in table 17. For comparison purposes, coal production in Washington, by year is shown in figure 38, and cumulative coal production in Washington, by county is shown in figure 39.

TABLE 17.--Production of coal in Pierce County and consumption in coke manufacturing by 5-year intervals (from, U.S. Bonneville Power Administration, 1963, p. 15)

Year	Average annual coal production, tons	Average annual coke production, tons
1885 through 1889	161,464	3,920
1890 " 1894	341,752	6,198
1895 " 1899	454,576	25,567
1900 " 1904	532,328	42,789
1905 " 1909	548,885	46,535
1910 " 1914	751,232	60,616
1915 " 1919	525,292	114,303
1920 " 1924	312,605	51,802
1925 " 1929	347,644	68,807
1930 " 1934	183,679	34,718
1935 " 1939	83,319	11,979
1940 " 1944	33,373	-
1945 " 1949	15,739	-
1950 " 1954	4,079	-
1955 " 1959	1,409	-

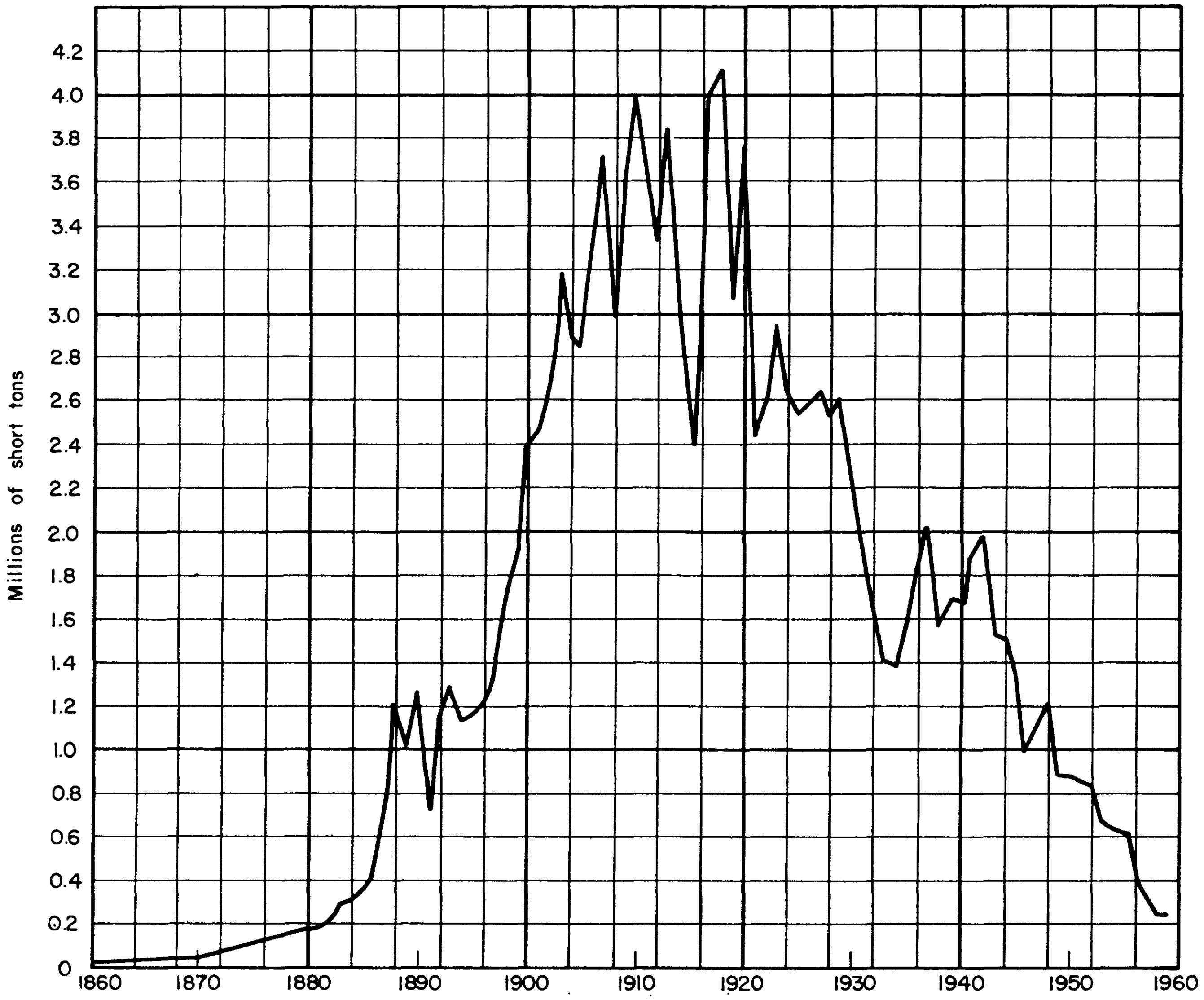

FIGURE 38.--Coal production in Washington, by year
(From Beikman and others, 1961, p. 9)

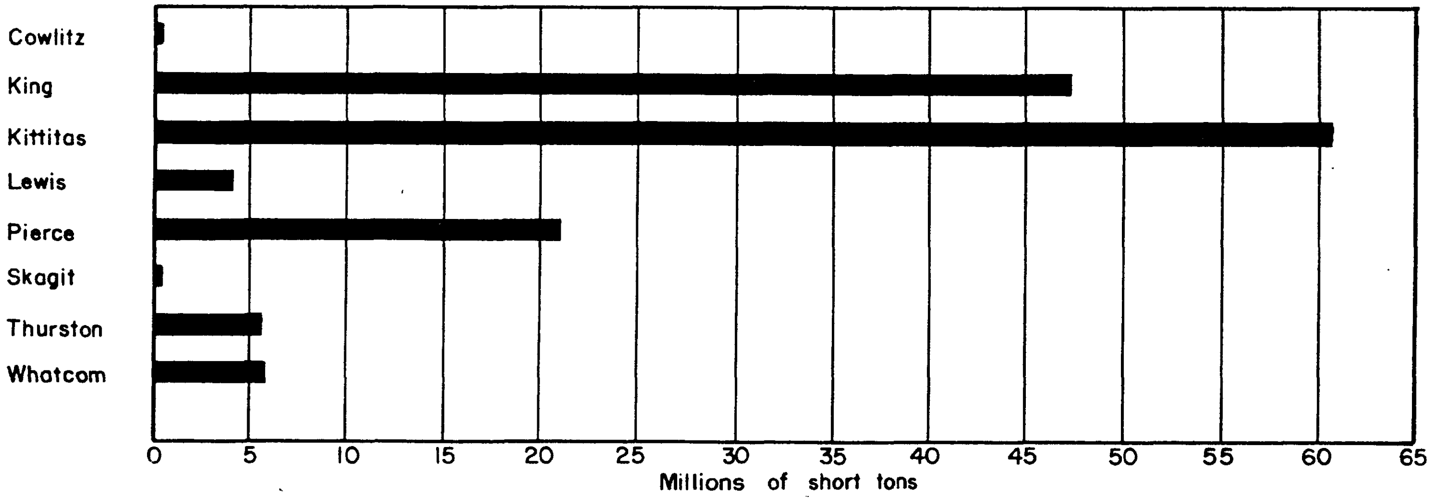

FIGURE 39.--Cumulative coal production in Washington, by county
(From Beikman and others, 1961, p. 9)

Coking Coal

Occurrence and development

Coking coal occurs in the Pacific Coast of the United States only in Washington and Alaska. In the past, most of the coking coal produced on the Pacific Coast was obtained from several coal beds in the Wilkeson-Carbonado coal field. The suitablilty of this coal for the manufacture of coke was recognized shortly after coal mining began in the 1870's, and the manufacture of coke in Washington was begun about 1880 when a few tons of pit coke were produced near Wilkeson. The earliest reported production of coke was 400 tons in 1884. In 1885, two beehive ovens were built at Wilkeson and by 1917, 160 ovens were operating in that area. Beehive ovens were built also at five other localities in the Wilkeson-Carbonado coal field and in 1921 there were 407 ovens at the six installations in the field (Daniels, 1941, p. 5). These installations were located as follows:

Carbonado - 71 ovens
Croker - 66 ovens
Fairfax - 60 ovens
Montezuma - 25 ovens
South Willis - 25 ovens
Wilkeson - 160 ovens

The Wilkeson-Carbonado and Fairfax-Montezuma areas are the principal source of coal suitable in quantity and quality for coking as indicated by the distribution of coke ovens.

Coal from the Wilkeson-Carbonado field was also used to manufacture gas and coke at byproduct coking plant in Seattle. The Seattle plant was in operation from 1914 through 1937.

Coking properties of coal

The coking properties of the coal in the Wilkeson-Carbonado coal field appear to be due to the physical and chemical changes that resulted from the close folding of the sedimentary rocks containing the coal beds. Information regarding the carbonizing properties of coal beds in the Wilkeson-Carbonado coal field and a comparison with physical and chemical properties of coke from other coal fields is contained in several U.S. Bureau of Mines publications. Among these are, washing and coking tests made by Belden and others (1910); agglutinating, coking and by-product tests of coal from the Wilkeson-Carbonado field conducted by Marshall and Bird (1931); Yancey and others (1932) investigated the friability, slacking characteristics, low-temberature carbonization assay and agglutinating value of Washington and other coals; Yancey and others (1939) summarized and the physical and chemical properties of coke made or used in Washington; Daniels (1941) and Yancey and others (1943) reported on beehive and byproduct coke-oven tests of Washington coals; Davis and others (1942) tested the carbonizing properties and described the petrographic composition of the Nos. 2 and 5 coal beds in the Wilkeson area; and, Davis and others (1952) investigated the carbonizing properties and blends of Washington coals with Utah coals.

The results of these tests show that coal from several beds in the Wilkeson-Carbonado coal field can be used in byproduct ovens and will yield a coke that can be used for most purposes. In general, the cokes manufactured from Wilkeson-Carbonado area coals are resistant to shatter degradation, will withstand breakage when handled, and are resistant to degradation by abrasion. These cokes are fairly combustible (ignition temperatures range from 460 to 570 C.), and the sulfur content is low enough to meet the requirements of foundary use. Daniels (1941, p. 63) stated that the principal objection raised in the past to the coking of Washington coals has been their high ash content. He suggested in further comments that the ash content, however, is not a factor in the ability of coal to coke but is primarily a cost factor in the selection or preparation of the coal used. Yancey and others (1943, p. 45), concluded that the high phosphorus content of some of the coals in the Wilkeson area may preclude their use in more specialized industries, such as ferroalloy manufacturing.

Coke production

Coke production in Washington, which centered chiefly in the Wilkeson-Carbonado coal field, reached a maximum of 125,872 tons in 1916, after which production declined steadily. Production from beehive ovens ceased in 1936, and that from byproduct coking plants terminated in 1937. In 1943 a coke plant was built in Tacoma and was operated intermittently until December 1944. About 75, 000 tons of coal mined at the Skookum slope near Wilkeson was used to supply the Tacoma plant, which produced 51,000 tons of coke. Some of the coke was used for metallurgical purposes, but most was used for domestic heating (Beikman and others, 1961, p. 10). The total production of beehive and byproduct coke through 1937 exceeded 2.3 million net tons. No coke has been produced in Washington since 1947.

The average annual coke production in Pierce County, Washington by 5-year intervals covering the period 1885 through 1935 is given in table 17 on page 86. Production of beehive and byproduct coke in Washington is summarized in figure 40.

Coking coal reserves

As estimated by the operating companies in the area in 1940, the reserve base of coking coal in the Wilkeson-Carbonado coal field was believed to be between 60 and 125 million net tons (Berryhill and Averitt, 1951, p. 6). The higher figure quoted above includes recoverable coal, including partings, within limits of depth, whereas, the more conservative figure of 60 million tons represents washed coal recoverable from a depth of 500 feet below the existing mine workings and from unmined tracts adjacent to the mines (Daniels, 1941, p. 16). The smaller figure considers losses incurred in mining and washing, and in this respect, is more realistic.

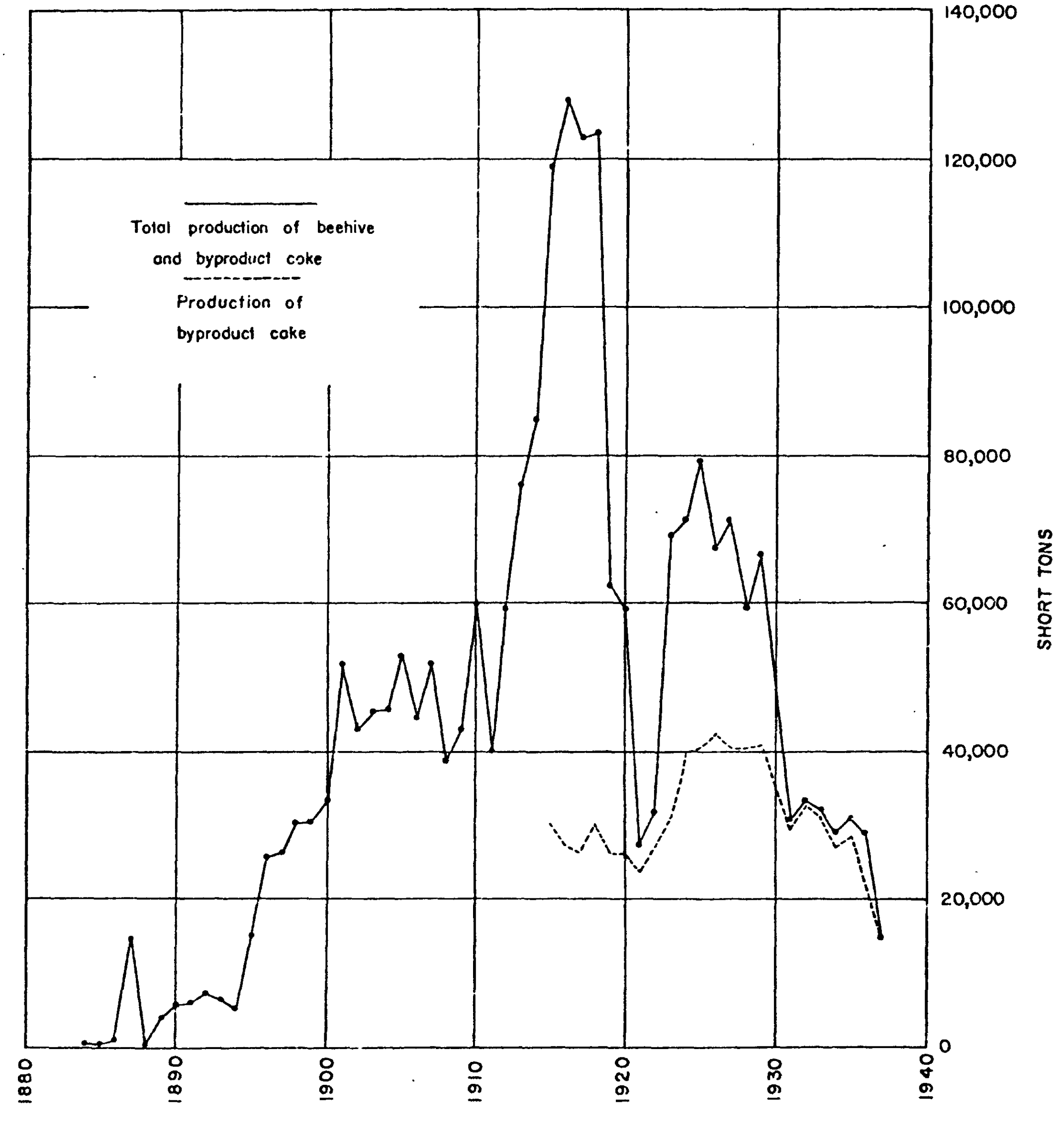

FIGURE 40.—CHART SHOWING PRODUCTION OF BEEHIVE AND BYPRODUCT COKE IN WASHINGTON
(From Beikman and others, 1961, p. 11)

MINING METHODS

Method Of Entry

Coal in the Wilkeson-Carbonado coal field was mined by underground methods. Topographic conditions, the presence of unconsolidated glacial deposits, and a dense forest growth have determined the methods of opening and limited the location of mines to those places where access was easy to both the coal and lines of transportation. The most favorable method of entry under these conditions has been drifts or water-level gangways driven on the coal from outcrops along ravines and stream beds. Those coal beds not directly accessable were reached by driving rock tunnels on drainage grades to cross cut the coal-bearing sequence. Some of these tunnels were driven from a point above water level in the deeper ravines in the area, and others were driven from older drift entries or water-level gangways within a mine. As the coal above water level became exhausted, that lying below water level was mined from slopes driven down the dip of the coal bed and pumps were installed to remove water. All of the mines, except some in the Wilkeson area, have slope operations to coal lying below water level.

General Mining Methods

The principal methods of working the steeply dipping coal beds in the Wilkeson-Carbonado field are the chute-and-pillar method, and to a much lesser extent, the brest-and-pillar method. Modifications of these two methods have been used which include a modified longwall and a "booming" method. The mining methods and how they were employed at the various mines within the Wilkeson-Carbonado field were explained in detail by Daniels (1914, p. 70-94), Evans (1924, p. 42-58), and Ash (1925, p. 836-862).

Mining Problems

Because of the complex structure of the Wilkeson-Carbonado coal field, mining is difficult. The coal-bearing strata have been folded and faulted and the coal beds dip at angles ranging from moderate to steep. In some of the mines more than one method of mining may be necessary to remove the coal. At places the coal beds are terminated and offset by high-angle reverse or normal faults. Dikes and sills of igneous rocks have intruded the coal-bearing sequence and at places the intrusion of these bodies markedly altered the characteristics as well as the structure of the coal beds. The roof rock of some of the coal beds is structurally incompetent siltstone or friable sandstone, and in some mines extensive timbering is necessary or some of the coal must be left in place to support the roof. Gas is present in considerable quantities in some of the mines, and an unusual amount was encountered along a well-defined zone which cuts diagonally across the workings on the Wingate coal bed at Carbonado. In addition to the problems enumerated above, much of the coal in the Wilkeson-Carbonado coal field is so friable that the coal must be supported to within a few feet of the advancing face which in past mining has required extensive timbering.

Mine Fires

No mines in the Wilkeson-Carbonado field are subject to fires from spontaneous combustion. Fires have occurred, but they have been started by ignition of the timber or other combustible material (Evans, 1924, p. 57).

Preparation of Coal

Practically all the coal mined in the Wilkeson-Carbonado coal field is cleaned at the surface. One of the major problems of developing the field in the past has been the difficulty of cleaning the coals to the ash specifications of prospective users. Most of the coal beds have a relatively high ash content and contain numerous partings of carbonaceous shale and bony coal as shown in figures 16-19, 21, 25, and 26. With few exceptions, the coals from the Wilkeson-Carbonado field present the most difficult cleaning problems encountered in this country. Information on cleaning coals from the Wilkeson-Carbonado field is available in reports by Belden and others (1910), Bird and Marshall (1931), Bonneville Power Administration (1963) and Geer (1964).

Extent of Mine Workings

Most of the easily accessible coal in the Wilkeson-Carbonado coal field has been mined, and part of the remaining estimated reserve base may be uneconomical to mine because of prior mining. The most extensive mining has been in the Wilkeson-Carbonado area, especially in the vicinity of Carbonado where the Carbon Hill Coal Co. and the Pacific Coast Coal Co. mined over 10 million tons of coal in mines north and south of the Carbon River. The workings south of the river extended to depths slightly below sea level on the Wingate coal bed. The Wilkeson Coal and Coke Co. mined over 3.6 million tons from its properties near Wilkeson, and the Pacific Coast Coal Co. produced more than 3.7 million tons at mines near Burnett. The mines on these three properties accounted for nearly 84 percent of the total production of coal in the Wilkeson-Carbonado field. The mine workings in the Melmont, Fairfax-Montezuma, and Spiketon areas are not very extensive, but they are in the most accessible coal in those areas. Mined-out areas of the principal coal beds in the Wilkeson-Carbonado field are shown in figures 27 through 36.

Condition of Mine Workings

Large-scale mining ceased at most places in the Wilkeson-Carbonado coal field in the late 1930's. The most recent sizable mine was the Skookum near Wilkeson which operated during 1943 and 1944, and briefly in 1952. The condition of the abandoned workings is unknown, however, they are probably unsafe because of caving, rotting timbers, mine gas, and water. Pools of water have probably accumulated at some places in the abandoned workings; most likely in mined-out areas lying below the natural drainage level. Mine-water pools that may exist in the abandoned workings would be supplied by direct connection of the workings with water-bearing glacial deposits which mantle much of the coal-bearing strata; and, from percolating ground water which would enter the pools from unmined coal beds and adjacent strata.

EVALUATION FOR HYDRAULIC MINING

Geologic And Technical Factors

Reserve base

The estimated reserve base of the Wilkeson-Carbonado coal field is summarized in table 16 on page 82. Several factors should be kept in mind in evaluating the estimated reserve base for hydraulic mining:

1. Estimated reserve base only covers areas of intensive mining where the data were sufficient to prepare an estimate. The estimate probably covers less than 50 percent of known coal-bearing area within the coal field.
2. The acquisition of additional geologic information about the structure, thickness, continuity, and quality of the coal in undeveloped areas will result in a substantial increase in the estimated reserve base.
3. Some of the coal included in the estimated reserve base will probably be uneconomical to mine because of the proximity of old mine workings.
4. About 60 percent of the estimated reserve base is in the Wilkeson-Carbonado area; most of the additional estimated reserves occur in the Spiketon area.
5. About 80 percent of the estimated reserve base in the Wilkeson-Carbonado area occurs in beds exceeding 42 inches in thickness; 44 percent of the estimated reserve base are less than 1,000 feet deep, and only 14 percent of the estimated reserves in the Wilkeson-Carbonado area occur at depths exceeding 2,000 feet.

Coal characteristics

Coal beds vary in thickness, extent, and character throughout the Wilkeson-Carbonado coal field. About 40 beds have been opened or mined in several isolated areas within the coal field. The coal ranges in rank from high-volatile A bituminous to low-volatile bituminous, has a low sulfur content, but contains a rather high ash content (8-23 percent) which presents some cleaning problems. The coal beds contain numerous thin to thick partings which are mined with the coal. The coal is quite friable and locally, in the vicinity of faults or where the coal beds are tightly folded, the coal is highly sheared. Most of the coal in the Wilkeson-Carbonado and Fairfax-Montezuma areas will coke whereas, coal in the Spiketon area is generally noncoking.

Accessibility

Topographic conditions and a mantle of glacial deposits limit access to the coal. Most of the accessible and easily mined coal has been mined and future operations will have to be undertaken at deeper levels, generally below the natural drainage level, in the extensively mined areas, or in undeveloped areas of the coal field where the structure, continuity, and quality of the coal beds is unknown.

Limiting factors

The intense structural deformation of the Wilkeson-Carbonado coal field imposes definite limitations on conventional mining plans. Owing to the numerous faults encountered in the coal field, discontinuities can be anticipated that will possibly alter previously adopted mining plans or restrict the use of some mechanized equipment. It is likely that highly fractured zones will be encountered which will limit mining. Igneous intrusions will also restrict mining especially in the southern part of the coal field where intrusives are more prevalent. Substantial quantities of gas encountered in some of the coal beds may impose further limitations on mining.

Water supply and quality

Water supply and quality of the water in the Wilkeson-Carbonado coal field appear to be adequate for hydraulic coal mining and are evaluated in Part 2 of this report.

General Mining Conditions

Cooley (1975, p. 10-1) enumerated desirable conditions for hydraulic mining to include:

1. Seam pitch angles above 5° to 8°.
2. Thick seams (6 to 50 ft. or more).
3. Fairly uniform pitch angle of seams without major undulations or faults which would interfere with maintenance of proper slope for flumes (usually 4°-7°), preferably permitting fluming to portal.
4. High-value coal (e.g., coking coal), not hampered by competition from lower cost strip mined coal in the region.
5. Hard floor rock, not attacked by water.
6. Soft friable coal, easily broken by a monitor jet.
7. Less than 2000 ft. of overburden and relatively stable roof rock which will cave in a predictable way, without major seismic bumps.
8. A deposit in an area without surface installations or waterways which would be affected by subsidence.
9. Availability of water and electric power nearby.
10. Low sulfur content of the coal and not excessive water inflow to the deposit which would cause a problem of disposal of acid mine water.
11. Location near customers for coal transport by rail, truck or slurry pipeline.
12. Local terrain and hydrology favorable for refuse disposal by lagooning without causing water pollution.

Several of the favorable conditions for hydraulic mining are found in the Wilkeson-Carbonado coal field; notably conditions 1, 4, 5, 8, 9, and 11 as outlined above are characteristic of the coal field. Conditions 2, 3, 5, 7, and 12 are uncommon in the coal field, and are discussed below:

Condition 2-Thick seams (6 to 50 ft.). Most of the coal beds in the Wilkeson-Carbonado field vary in thickness and quality, and average from 2 to 8 feet in thickness and thus are more appropriately classed as thin seams.

Condition 3-Fairly uniform pitch angle of seams without major undulations or faults etc. Uniform dips prevail in only limited areas of the closely folded and faulted Wilkeson-Carbonado coal field. The coal beds maintain a fairly uniform dip along the eastern margin of the field; however, the coal beds in that area generally are noncoking and commonly have a higher ash content than the coal beds occurring elsewhere in the coal field. Also, faults and igneous intrusions encountered in the coal field will be a major limiting factor in site selection and mining plan but do not necessarily impose insurmountable problems.

Condition 5-Hard floor rocks, not attached by water. The properties of the floor rocks are difficult to assess because detailed information is lacking. Available data indicate that some of the coal beds grade to bony coal and carbonaceous shale at the base of the bed, underlain by several feet of shale which is generally underlain, in turn, by a comparatively thicker sequence of interbedded siltstone and sandstone. The floor rock of other coal beds in the area is composed of slightly friable siltstone and sandstone. About 18 inches of poorly developed underclay was noted at the base of the Wilkeson No. 3 coal bed in a bedrock exposure along Gale Creek during the course of the authors brief reconnaissance investigation of the Wilkeson-Carbonado coal field. Quite commonly underclays swell and heave when throughly wetted; however, no apparent swelling or heaving was detected in the highly weathered claystone observed along Gale Creek.

Condition 7-Less than 2,000 ft. of overburden and relatively stable roof rock which will cave in a predictable way. Overburden conditions, particularly the presence of thin to thick unconsolidated glacial deposits over much of the coal-bearing sequence, and topographic conditions, impose some limitations on the location and type of entry. Only general information is available on roof conditions. The roof rock varies from bed to bed. Thin to thick sequences of shaly sandstone and sandstone appear to be the most common roof rock, although at places the coal beds are overlain by several inches to as much as 30 feet of shale. Stratigraphic intervals between principal coal beds vary between 50 and 500 feet in thickness. At places, the interval between principal coal beds is comparatively thin and is commonly comprised of sandstone that might be expected to cave in a predictable manner, however, alternating thin beds of sandstone, siltstone and shale form sequences as much as 100 feet thick separating some of the principal coal beds and might cause some problems. At other places, where the interval between principal coal beds exceeds 100 feet in thickness, the strata in these intervals are comprised of thick sequences of sandstone interspersed with thinner sequences of siltstone, shale, carbonaceous shale, coal, and impure coal. In general the sandstone strata are moderately indurated, thin to very thick bedded, commonly cross-bedded and lenticular. The shale and siltstone are commonly quite friable and range from laminations a fraction of an inch thick to bedded sequences as much as 25 feet thick. Considerable variation in the characteristics of the overburden above principal coal beds, and poor to good roof conditions should be anticipated in the Wilkeson-Carbonado coal field.

Condition 12-Local terrain and hydrology favorable for refuse disposal by lagooning without causing water polution. The Wilkeson-Carbonado coal field occurs in an upland area characterized by a rather flat northwest-sloping surface that has been deeply dissected by several streams and a river which drain the area. Access to the coal is difficult and is generally along the several steep-sided and narrow valleys. If entry is made from one of these narrow valleys, limited area will be available near the mine for the construction of surface installations such as lagoons for impounding water or refuse. Careful consideration should be given to the construction of impounding lagoons should they be required; quite probably very stringent limitations would be imposed on the construction of such facilities because of potential safety and contamination hazards they impose.

Potential Demonstration Site

An undeveloped tract of about 3,000 acres lying southeast of Carbonado and north of Fairfax in secs. 2, 10, 11, 15, and the west half of 14, in T. 18 N., R. 6 E., might offer the best potenial for a demonstration site for hydraulic coal mining. This area was prospected in the early 1920's (Marshall and Bird, 1931) and was under consideration for development when mining activities ceased in the area. Further detailed investigations of the geology and hydrology of the area would be required to evaluate the mining potential of the area. Reserve base estimates are not available for this part of the coal field due to the lack of specific detailed information required for such estimates; however, it is apparent from previous exploration that the area contains sizable resources of coking coal. As in most areas of the coal field, the structural configuration of the coal beds would impose definite limitations on the mining plan. The structure appears to be least complicated in sec. 2 and 11 along the east flank of the Wilkeson anticline. Coal beds in the area occur in the Carbonado Formation and are thought to be correlative to those mined in the Wilkeson mines immediately north of the area. Several of the coals are exposed along Gale Creek near the site of a recent (1976) field demonstration of hydraulic borehole mining of coal conducted by Flow Research Inc. for the Bureau of Mines (Contract No. H0252007).

Summary Evaluation

There are both favorable and adverse conditions for hydraulic mining in the Wilkeson-Carbonado coal field and it is evident from our preliminary site evaluation that more detailed investigations of the geology of the area are necessary, and that probably a period of experimental mining would be required before a realistic appraisal of the hydraulic mining potential can be made. Additional geologic exploration would be required to establish the resource base, coal quality, and mining conditions, especially in the undeveloped parts of the coal field. Geologic exploration would be hampered by the complicated structure of the coal field, the presence of thick glacial deposits over much of the area, and the paucity of exposures. These adverse conditions also will make the selection of sites for an effective borehole drilling program difficult. Other means of obtaining the information necessary to make an accurate assessment of the area should be explored. Geophysical exploration techniques including magnetic and high resolution shallow seismic surveys, coupled with core drilling in selected areas might prove the least costly means of obtaining the necessary data for evaluation of the Wilkeson-Carbonado coal field.

HYDRAULIC MINING POTENTIAL IN OTHER AREAS

Other coal-bearing areas in Washington contain moderate to steeply dipping coal beds and may have some potential for hydraulic coal mining. Among these areas and of primary interest is the Roslyn coal field which occupies an area of about 30 square miles in Kittitas County. Eight major coal beds ranging from 2 to 21 feet in thickness have been mined in the field. The reserve base of coal in the Roslyn field is estimated to be about 240 million tons, all classed as bituminous (Beikman and others, 1961, p. 25). Some of the coal is weakly coking.

The major structure in the Roslyn field is a broad northwest-trending, southeast-plunging syncline. Strata on the northern flank of the syncline dip about 10° to the southwest. Along the southern margin of the field the structure is more complex and consists of a series of rather tightly folded anticlines and synclines. Strata on the flanks of these subsidary folds dip as much as 40°. The structure of the Roslyn field, which has been fairly well defined by extensive mining on the Roslyn No. 5 coal bed, is simple in comparison with the complexly folded and faulted Wilkeson-Carbonado coal field. Also, mining conditions in the Roslyn field are more favorable than those in the Wilkeson-Carbonado field, and the recovery of coal from the Roslyn No. 5 coal bed has been about 80 percent (Beikman and others, 1961, p. 23). This is well above the average of most underground coal mining operations in Washington.

Hydraulic coal mining was attempted in the Roslyn coal field in the early 1960's. Tests were conducted in the Roslyn No. 5 coal bed to evaluate the extracting of coal with a high-pressure water jet. The results were encouraging and demonstrated that coal pillars left from previous conventional mining in the Roslyn No. 5 bed could be mined more economically by hydraulic methods than by conventional mining methods (Nasiatka and Badda, 1963, p. 16). In development work, however, productivity by hydraulic mining methods was considerably less than by conventional mining methods (Price and Badda, 1965).

The coal deposits in the Green River district in the southern part of King County also may have some potential for hydraulic coal mining. The district includes about 55 square miles of coal-bearing rocks in a number of isolated mines and areas separated by broader areas of glacial deposits. Coal beds in the area range from 2 to 25 feet in thickness. Most of the coal is high-volatile B bituminous rank and some has coking qualities. The coal has a low sulfur content and the ash content ranges from 2.2 to 31.8 percent and averages 14 percent. The reserve base of coal in the Green River district is estimated to be 357 million tons. The McKay coal bed has been mined most extensively but there has been substantial production from at least 12 other coal beds in the district (Livingston, 1974, p. 48).

The coal-bearing rocks in the Green River district have been extensively folded into a series of north- to northeast-trending anticlines and synclines and are cut by numerous faults. Some of the faults have displacements of over 1,000 feet. In general, the structure of the Green River district is not as complex and mining conditions are probably more favorable than in the Wilkeson-Carbonado coal field.

CONCLUSIONS AND RECOMMENDATIONS

Appreciable amounts of coking coal occur in the complexly folded and faulted Wilkeson-Carbonado coal field. Difficult mining conditions in the coal field have been a serious problem in the development of the field. Solution to the problem will require ingenuity and resourceful engineering.

Owing to the complicated geologic structure and a cover of glacial deposits, comparatively little is known about the quantity, quality, or condition or the coal except in areas where extensive mining has been conducted in the past.

The structure and stratigraphic succession of the central part of the Wilkeson-Carbonado coal field in the Wilkeson-Carbonado area is fairly well defined. The central part of the field contains the best coking coal in the coal field.

The Melmont and Fairfax-Montezuma areas contain low-volatile coking coals but in these areas the structure and correlation of the coal-bearing sequence is uncertain.

The Spiketon area contains appreciable amounts of comparatively higher-ash coal most of which has poor coking qualities or is noncoking. In general the structure of the coal field is least complicated in the Spiketon area.

The most accessible and easily mined coal in the Wilkeson-Carbonado coal field, that above drainge level, has been mined, and part of the remaining coal may be uneconomical to mine because of the many old mine workings.

Future operations in the Wilkeson-Carbonado field will probably have to be undertaken at deeper levels and generally below natural drainage level, or in previously undeveloped areas of the coal field in which very little is known about the configuration and continuity of the coal-bearing sequence.

One undeveloped tract of about 3,000 acres lying southeast of Carbonado and north of Fairfax in secs. 2, 10, 11, 15, and the west half of 14, in T. 18 N., R. 6 E. might offer the best potential for a demonstration site but detailed investigation of the geology and hydrology of the area is recommended prior to any experimental mining.

Geophysical exploration techniques including magnetic and high resolution shallow seismic surveys, coupled with core drilling in selected areas might prove the least costly means of obtaining the necessary data for evaluation of the Wilkeson-Carbonado coal field.

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EVALUATION OF THE
WILKESON-CARBONADO COAL FIELD,
PIERCE COUNTY, WASHINGTON
FOR HYDRAULIC COAL MINING

Part two - Water Resources

RECONNAISSANCE EVALUATION OF WATER RESOURCES FOR HYDRAULIC COAL MINING, WILKESON-CARBONADO MINING DISTRICT, WASHINGTON

By F. A. Packard and W. L. Haushild

Prepared by the Water Resources Division, Tacoma, Washington, 1977

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ILLUSTRATIONS

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METRIC CONVERSION TABLE

Multiply		By	To obtain
Length:	inches	25.40	millimeters (mm)
	feet (ft)	.3048	meters (m)
	miles (mi)	1.609	kilometers (km)
Area:	square miles (mi^2)	2.590	square kilometers (km^2)
Mass:	tons (2,000 lbs)	907.2	kilograms (kg)
Flow:	cubic feet per second (ft^3/s)	.02832	cubic meters per second (m^3/s)
Concentration:	parts per million	1.000	milligrams per liter (mg/L)
Temperature:	degrees Fahrenheit	subtract 32 multiply remainder by 0.5556	degrees Celsius (°C)

RECONNAISSANCE EVALUATION OF WATER SUPPLY AND QUALITY FOR HYDRAULIC COAL MINING, WILKESON-CARBONADO MINING DISTRICT, WASHINGTON

By F. A. Packard and W. L. Haushild

ABSTRACT

Streamflow and water quality in the Carbon River and South Prairie Creek drainages of the Wilkeson-Carbonado Mining District are indicated to be more than adequate for use in hydraulic coal mining with a recycled water system. Wilkeson Creek also has water of satisfactory quality for such use. However, if the draft rate is relatively high along this creek, some storage of water may be necessary for mining during the low-flow periods of late summer and early fall.

Ground-water flow into many abandoned mines of the district is adequate to provide a supply of water for projects which entail mine reentry with hydraulic mining of coal on a small scale (1 million tons per year).

Samples were taken of Skookum area mine (5Q, fig. 1) discharges and of water used in a U.S. Bureau of Mines borehole hydraulic-mining project near Wilkeson. Analysis of these samples indicates that suspended sediment and high water temperatures would be the major problems associated with disposal of waste water from hydraulic mining in the district. In instances where presently abandoned mines are to be reentered, dissolved sulfides will be the main water-disposal problem.

INTRODUCTION

The Wilkeson-Carbonado mining district and streams studied are located in the western foothills of the Cascade Range of Washington State (fig. 1). The purpose of this study was to evaluate the water resources of the mining district and describe any limitations that exist in using this water for hydraulic coal mining. The study covers water supply and quality in the larger streams and some of the water-quality problems that might be found if old mines are reentered for the purpose of mining with hydraulic equipment.

The study was made by the U.S. Geological Survey under an agreement with the U.S. Bureau of Mines.

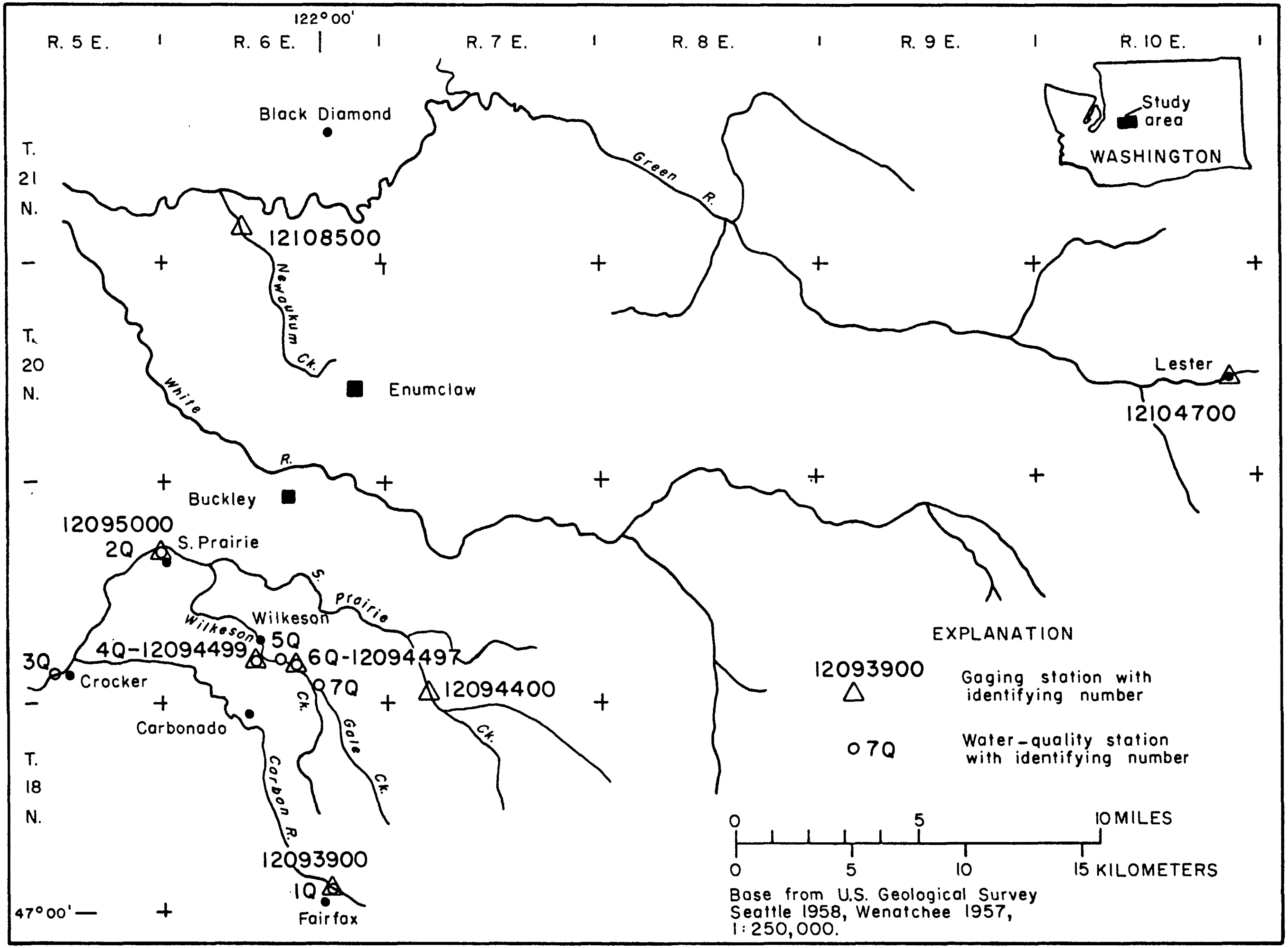

FIGURE 1.--Major streams and data-collection sites, in study area.

WATER QUANTITY

Three types of hydrologic analyses provide information that may be of use to the designer of a water-supply system. The analysis of monthly discharge data indicates the timing and magnitudes of high and low streamflows. The low-flow-frequency analysis provides magnitudes and frequencies of low flows for several periods of consecutive days. The draft-storage-frequency analyses provide bases from which minimum storage required for specific draft rates may be estimated.

Precipitation and streamflow.--Mean annual precipitation ranges from about 45 inches at the lower elevations in the study area to more than 100 inches at the higher elevations (fig. 2; U.S. Weather Bureau, 1965). The seasonal distribution of precipitation in the area has a peak in November-January, a gradual decrease to a low in June-July, and an increase to the next peak. (See example in fig. 3a.) Precipitation as snow occurs at all elevations, but both snowfall and snow accumulation increase with elevation. Snowfall usually starts in November or December and accumulation usually peaks in March. The maximum accumulation of snow in the vicinity of Carbonado is normally 1 to 2 feet. The storage of a substantial portion of the precipitation as snow, and its melting in the spring or early summer, are major factors contributing to summer and fall streamflows in the area.

In the study area, the total annual runoff from a stream basin depends greatly on the basin size and the total annual precipitation on the basin; the seasonal pattern of runoff depends mainly on the amount of snowfall and the timing of the subsequent melting of the snow. The monthly streamflow data in table 1 indicate different seasonal patterns of runoff for some streams in the area. As an example of the pattern of much snowfall and a relatively late snowmelt, discharge of the Carbon River (fig. 3b) has two peaks--one in December-January and another in May-June--and two lows--one in March-April and another in September-October. The effects of snowfall on runoff of streams draining the lower lying basins in the area become relatively unimportant, and the seasonal pattern of runoff is single-peaked--similar to the seasonal pattern of precipitation; for example, see figure 3c for Newaukum Creek. The mean monthly streamflows (table 1) at the stations on South Prairie Creek and Green Canyon Creek also follow a double-peak pattern. The main peak is in December-February, a lesser peak occurs either in April or June, and flow is minimum in August-September. This pattern of runoff occurs where snow is a significant, but not predominant, percentage of the annual precipitation and where snow melts relatively early in some upstream basins.

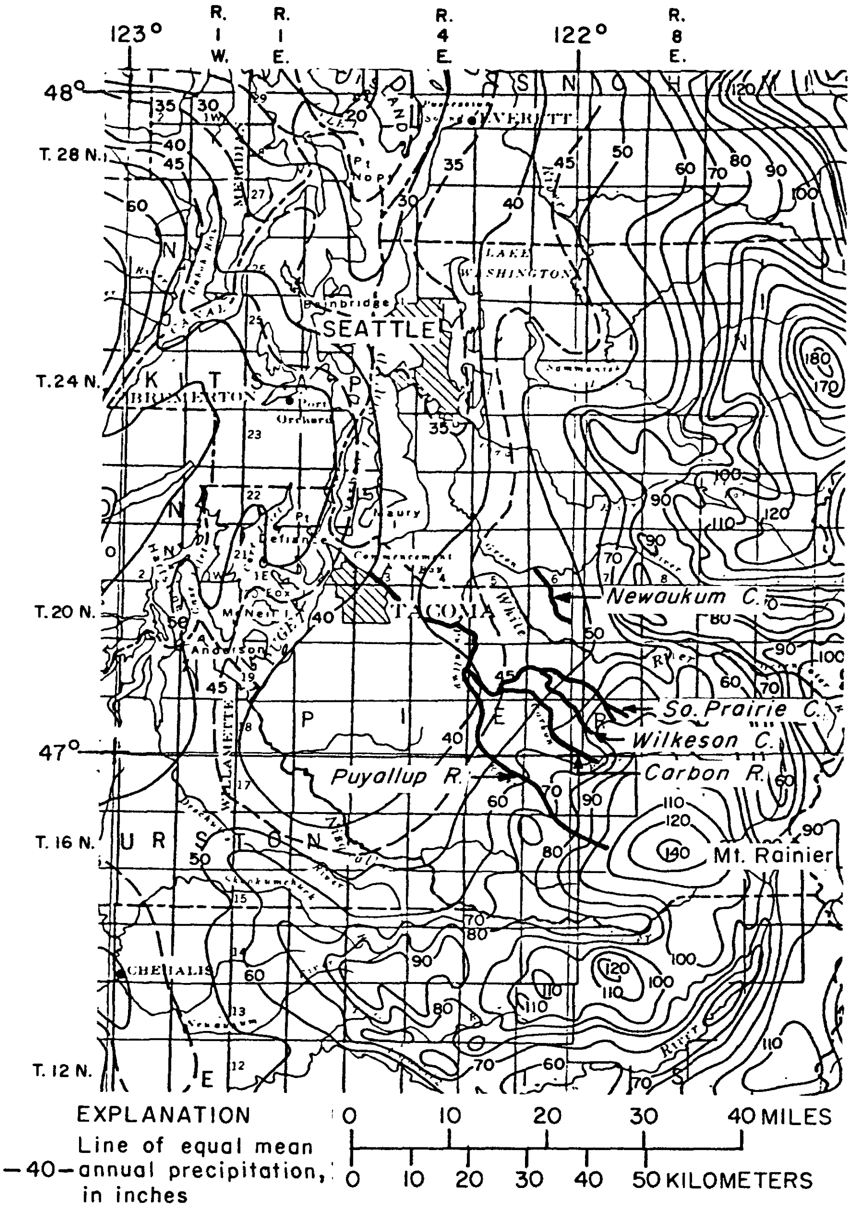

FIGURE 2.--Regional precipitation patterns in the southern Puget Sound-Cascade foothills area (from U.S. Weather Bureau, 1965).

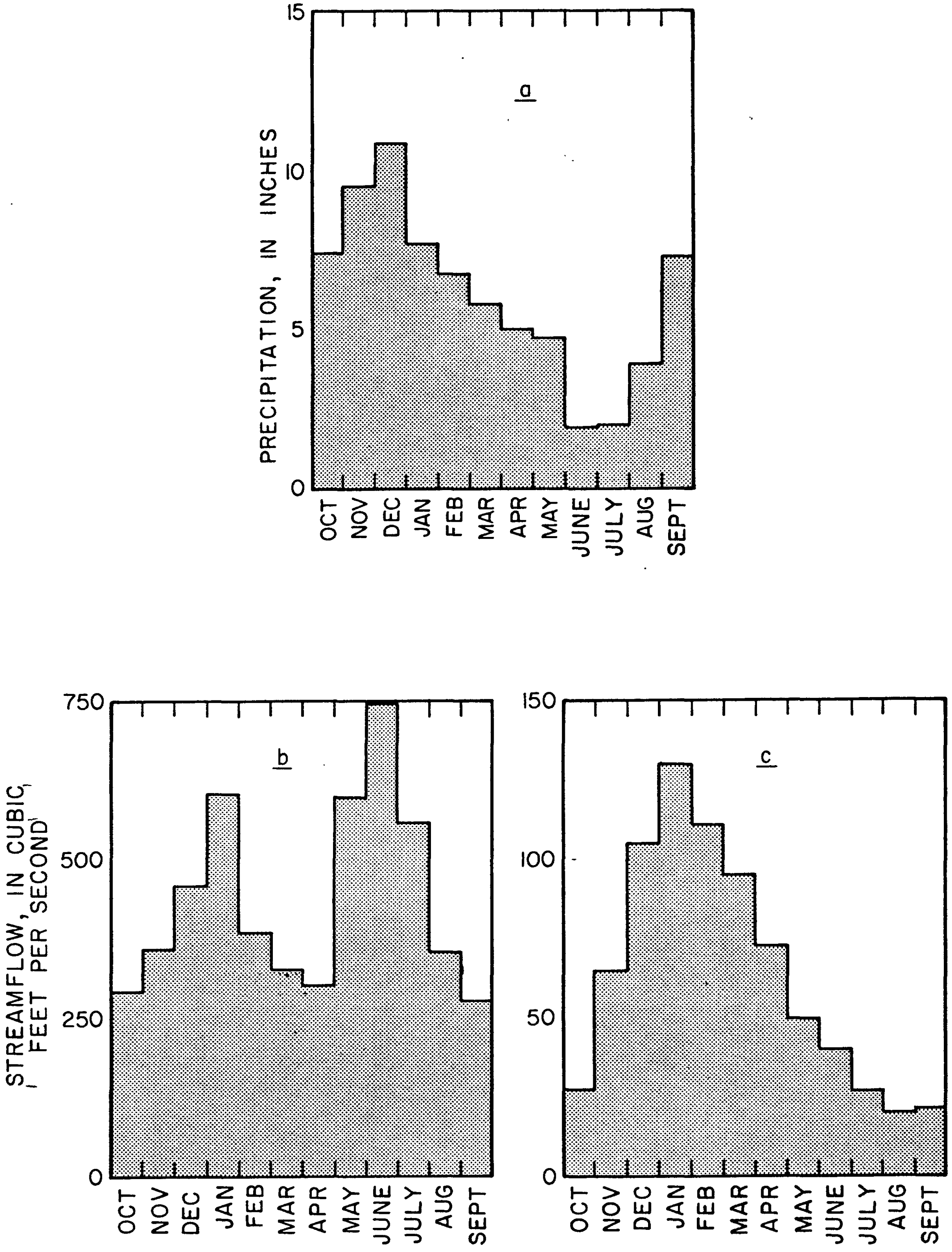

FIGURE 3.--Mean monthly precipitation at Carbonado 8 SSE (a), and mean monthly streamflows of Carbon River at Fairfax (b) and of Newaukum Creek near Black Diamond (c).

TABLE 1.--Monthly and annual discharges of selected streams near Wilkeson Creek

Station number and name		Drainage area (mi^2)	Period of record	Maximum (max.), mean, and minimum (min.) monthly and annual flows for period of record, in cubic feet per second													
					Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
12093900	Carbon River at Fairfax	76.2	1966-75	Max.	521	525	718	904	638	879	420	807	1,060	828	433	463	551
				Mean	286	363	459	601	384	326	301	590	743	554	354	274	437
				Min.	109	245	240	282	131	155	134	351	412	365	257	186	315
12094400	South Prairie Creek near Enumclaw	22.4	1964-68	Max.	104	140	219	279	191	103	134	157	237	120	91.0	107	127
				Mean	80.5	111	143	193	127	86.5	110	136	146	66.9	49.4	54.5	109
				Min.	61.3	63.4	68.3	104	51.3	70.2	59.3	111	84.0	41.1	21.1	19.8	82.4
12095000	South Prairie Creek at South Prairie	79.5	1949-71	Max.	349	665	728	683	656	527	371	463	439	246	193	233	320
				Mean	161	309	382	409	352	267	292	263	229	113	68.2	79.0	243
				Min.	34.0	35.2	61.5	126	133	157	192	150	112	51.3	36.5	35.2	170
12104700	Green Canyon Creek near Lester	3.23	1960-70	Max.	7.90	25.1	25.5	35.4	38.8	21.7	27.3	22.6	21.1	8.62	4.95	7.81	15.0
				Mean	4.76	11.6	17.7	25.1	21.3	16.7	18.4	14.7	9.18	4.93	3.22	3.10	12.5
				Min.	2.35	2.55	4.55	11.6	4.19	12.4	12.4	9.57	5.45	3.55	2.55	1.79	8.4
12108500	Newaukum Creek near Black Diamond	27.4	1945-75	Max.	58.9	146	225	252	222	215	109	83.2	74.5	40.1	30.0	39.2	85.9
				Mean	26.9	65.7	104	130	111	94.0	72.6	49.9	40.1	27.2	21.1	21.7	63.5
				Min.	9.42	10.1	11.4	62.6	47.9	51.2	44.9	33.3	25.4	17.7	12.8	13.2	41.9

Low flows.--The low-flow-frequency relations were determined from daily streamflow data for the four stations listed in table 1 that have at least 10 years of historical record. The results are given in table 2. For example, as shown in the table, the low flow of the Carbon River at Fairfax for 14 consecutive days in any year has a probability of 50 percent (chance of 1 in 2) of not exceeding 150 ft^3/s and a probability of 2 percent (chance of 1 in 50) of not exceeding 78 ft^3/s. Characteristically, as the number of consecutive days is increased the low flows at a given probability of nonexceedance increase much more in basins where streamflows have double peaks (Carbon River and South Prairie Creek) than in basins where streams have single peaks (Newaukum Creek). This dissimilarity in rate of increase indicates that low flows of single-peak streams persist longer than they do for double-peak streams.

The mean 7-day low-flow-frequency relations for the Wilkeson Creek stations (table 2) were estimated from correlations of flows measured several times during 1976-77 at the stations with daily mean flows on concurrent days at Newaukum Creek near Black Diamond. To estimate the low-flow frequencies, correlations were extended beyond the observed data, as shown in figure 4. For these estimates, the basic assumptions are that (1) the extensions represent the correlations between the appropriate discharges of the streams, and (2) the use of the correlations to estimate low flows in Wilkeson Creek from low flows in Newaukum Creek is valid.

Draft-storage-frequency relations.--A water diversion from a stream may be either a continuous or an intermittent withdrawal (draft) at either a constant or a variable rate. If the draft rates are large compared to the low flows of the stream, storage of water may be required. The designer of a water-supply project often can deduce whether storage is required from an examination of low-flow-frequency data, such as that given in table 2. For example, a draft of a few cubic feet per second probably would not require storage if the water supply is obtained from the Carbon River, South Prairie Creek, or Newaukum Creek. However, State regulations pertaining to streamflow may require that at a specified low streamflow, further withdrawal is stopped. For some streams, such as Green Canyon Creek or Wilkeson Creek, even a low-draft rate may require storage of water for a subsequent draft.

TABLE 2.--Low-flow-frequency data for stations on Wilkeson Creek and nearby streams

Station number and name		Consecutive number of days	Mean streamflow (ft^3/s) for indicated number of days and probabilities of nonexceedance (percent)				
			50%	20%	10%	5%	2%
12093900	Carbon River at Fairfax	7	130	110	95	85	74
		14	150	120	110	93	78
		30	180	140	120	100	86
		60	200	160	140	130	110
		90	260	220	200	180	160
		120	280	240	230	210	200
12095000	South Prairie Creek at South Prairie	7	38	31	28	27	26
		14	40	33	30	29	28
		30	44	36	34	32	31
		60	54	41	37	34	32
		90	67	49	42	37	33
		120	87	62	52	45	38
12094497	Wilkeson Creek at Snell Lake Road at Wilkeson	7	5.7	4.4	3.8	3.3	3.3
12094499	Wilkeson Creek near schoolhouse at Wilkeson (drainage area of 23.54 mi^2)	7	6.6	5.2	4.5	3.9	3.9
12104700	Green Canyon Creek near Lester	7	2.0	1.7	1.6	1.5	1.4
		14	2.1	1.7	1.6	1.5	1.5
		30	2.3	1.9	1.8	1.7	1.6
		60	2.6	2.1	2.0	1.9	1.8
		90	2.9	2.4	2.2	2.1	2.0
		120	3.4	2.7	2.5	2.4	2.3
12108500	Newaukum Creek near Black Diamond	7	16	14	13	12	12
		14	17	15	14	13	12
		30	18	15	14	14	13
		60	20	17	15	14	13
		90	21	17	16	15	14
		120	22	19	17	16	15

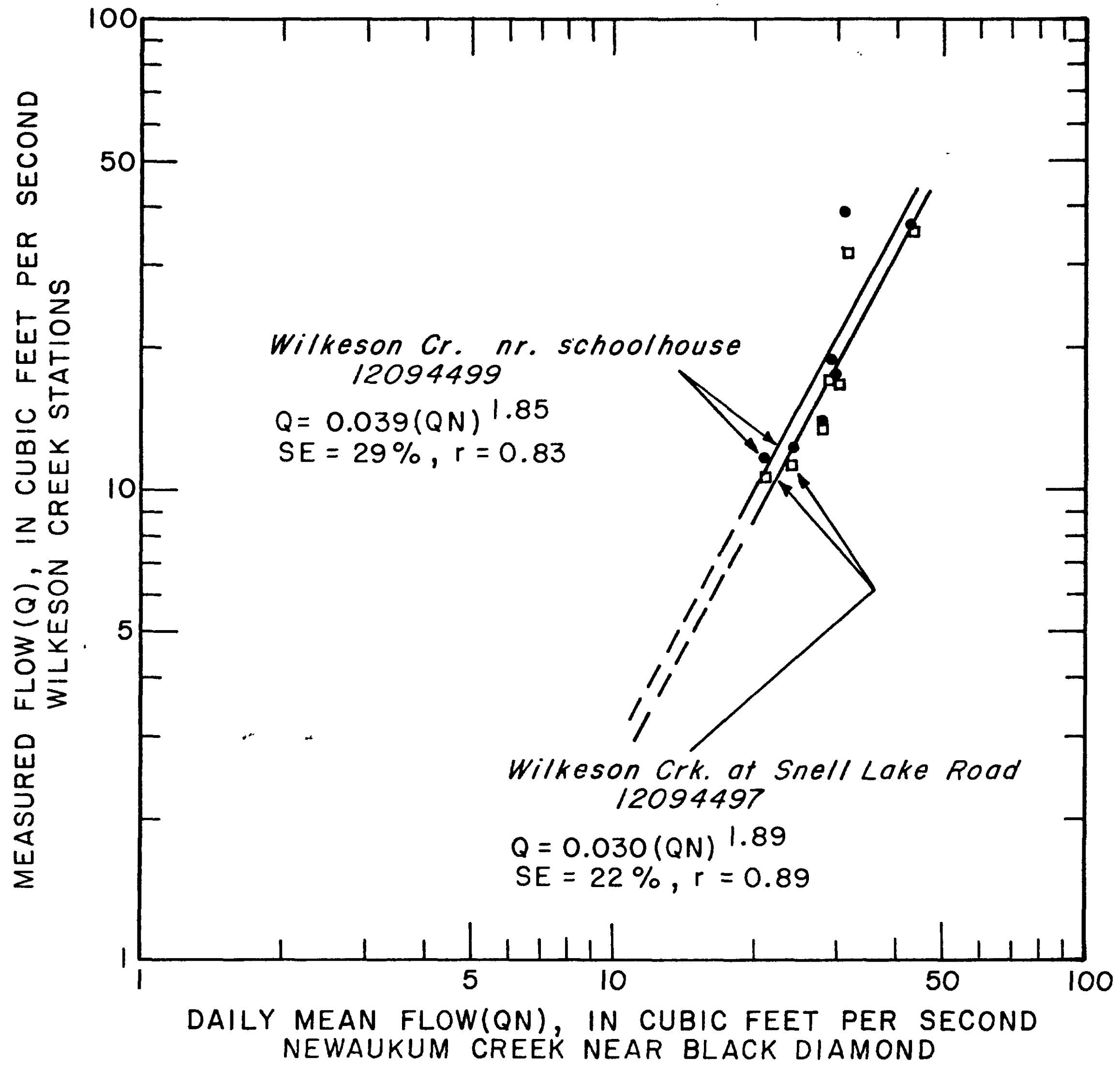

FIGURE 4.--Relations of discharges at Wilkeson Creek stations to that of Newaukum Creek near Black Diamond.

Riggs and Hardison (1973) present a method for using low-flow-frequency relations to estimate the storage required for a uniform draft rate. The storage required for losses from evaporation is not included. The draft-storage-frequency (DSF) relations estimated from low-flow-frequency relations for Green Canyon Creek near Lester and for Wilkeson Creek at Wilkeson are given in figure 5. The low-flow-frequency relations for Wilkeson Creek were estimated by using Newaukum Creek low-flow-data and the correlations shown in figure 4; however, because the average of the relations for the two stations was used, only one set of DSF relations was determined. The DSF relations (fig. 5) may be used to estimate the minimum storage required for a specified uniform draft rate. For example, for a draft rate of 10 ft^3/s from Wilkeson Creek (fig. 5a), the chances are 1 in 2 (50-percent nonexceedance probability) that a storage of at least 110 acre-feet would be required in any year, and chances are 1 in 20 (5-percent nonexceedance probability) that the storage required in any year would have to be at least 950 acre-feet.

Mine discharge and ground water.--In the Skookum mine area near Wilkeson (fig. 6) eight measurements of mine discharge were made over a 9-month period during 1976-77. The average discharge from the Skookum Slope mine (station #1, fig. 6) during this period was 0.03 ft^3/s, and the average discharge from the adjacent but separate mine system was 1.3 ft^3/s (three points of discharge at stations 2, 4, and 5, fig. 6). If the latter mine--or similarly sized mines in the district--is reentered, the ground-water flow into the mine should offer an adequate water supply for hydraulic mining, assuming a starting requirement of 20 acre-ft and a consumptive use of 50 acre-ft/yr (Cooley, 1975).

Ground water from wells also could be used to supply water for hydraulic mining. The best aquifers probably are in the alluvial materials along the major streams. However, surface-water supplies are so plentiful and so reliable that seldom would there be a need for supplemental ground-water supplies.

Discussion.--The designer of a surface-water supply system must consider many things including: (1) the amount of water required for the specific use; (2) the evaporation and other losses; and (3) the minimum flow at which withdrawals would be restricted. (The minimum flow of a given stream is usually set by State law to protect the stream biota and (or) to meet higher priority water uses downstream.) The continuing water supply needed for a coal-production rate of a million tons per year (Cooley, 1975) is small enough that it likely could be provided without storage, by any of the streams discussed herein. The initial 20 acre-feet needed for beginning hydraulic mining might require either withdrawal over a period of several days during low-flow periods or beginning the operation during periods of higher flow of Wilkeson Creek. Large water withdrawals for hydraulic mining of large quantities of coal or for transporting coal as a slurry in pipes may require water-storage facilities on Wilkeson Creek.

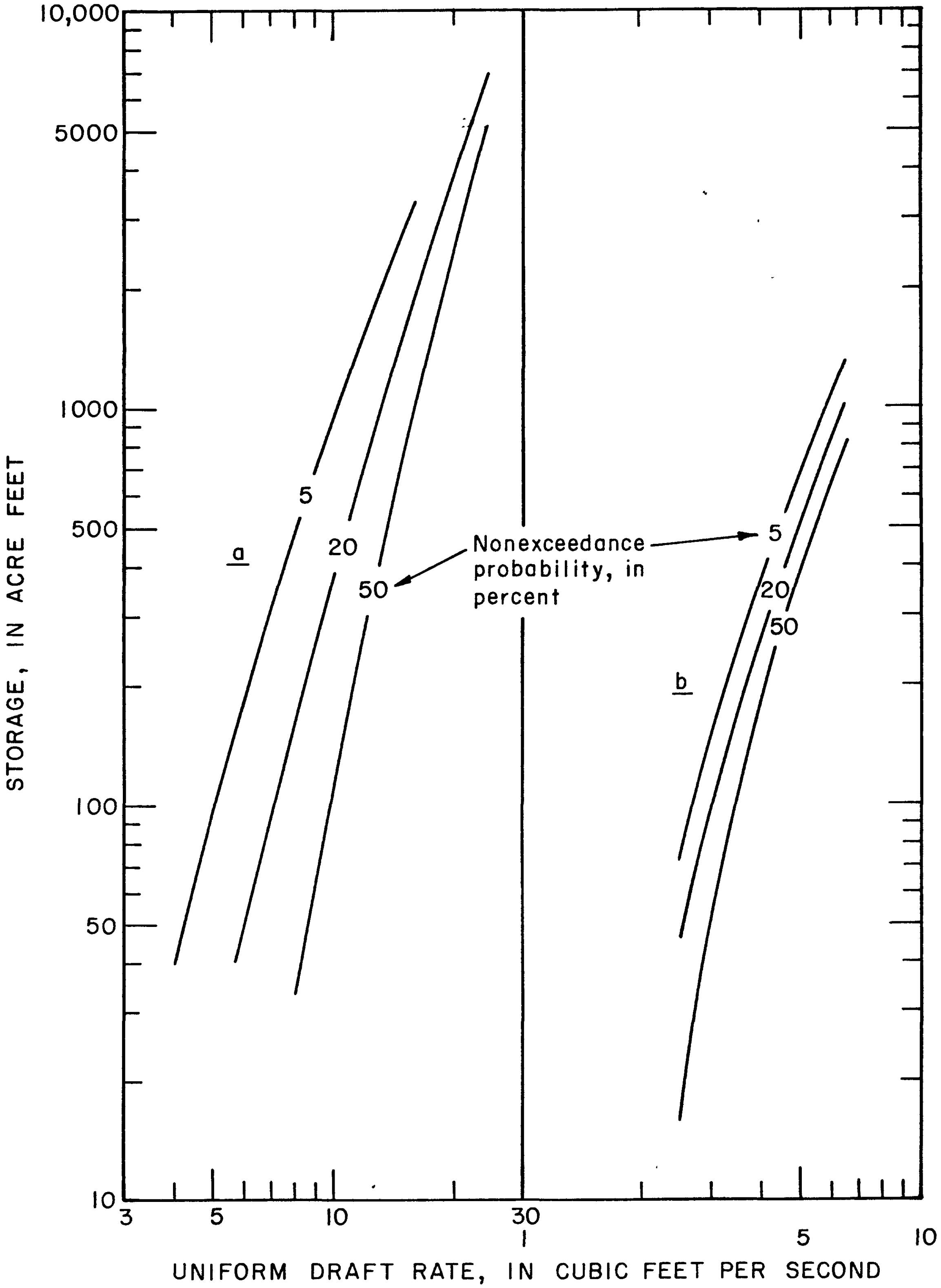

FIGURE 5.--Relations of storage-draft frequencies for Wilkeson Creek stations (a) and Green Canyon Creek near Lester (b).

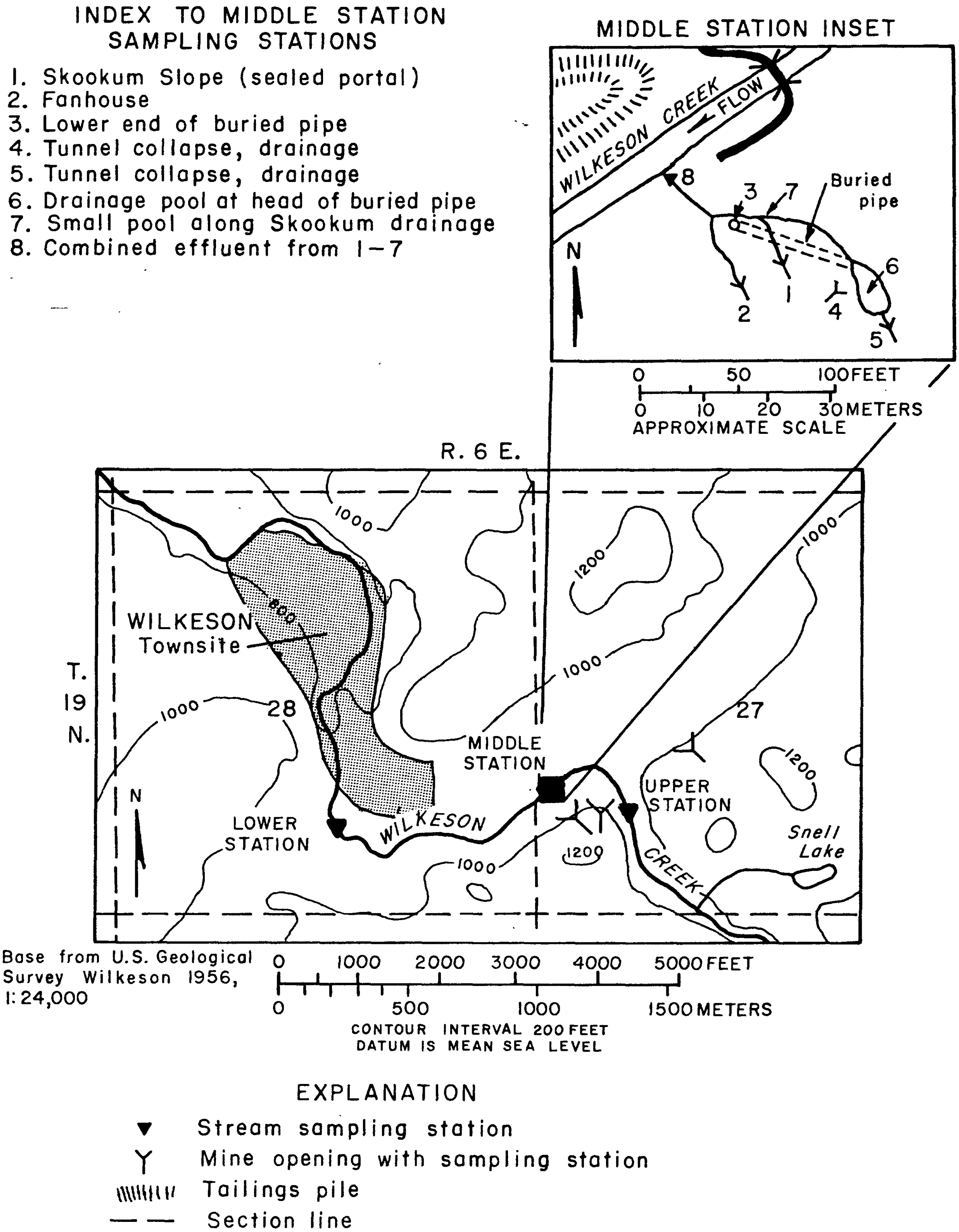

FIGURE 6.--Locations of Wilkeson Creek, Skookum mine area, and data-collection stations.

WATER QUALITY

General.--Discussion of water quality is designed to answer three questions: (1) Is the quality of water in the Carbon River, South Prairie Creek, and Wilkeson Creek adequate for use in hydraulic mining equipment; (2) Is drainage water from abandoned mines in the Wilkeson-Carbonado mine district (Beikman, 1961) of such low quality that it presents a significant water-treatment and disposal problem if the mines are reentered; (3) What changes in the local stream-water quality would be brought about by hydraulic mining of the coal?

Quality of stream water.--Water in the Carbon River at station 1Q (fig. 1) carries small amounts of dissolved solids and small to moderate amounts of suspended solids (table 3). On the average, the pH of these waters is in the neutral to slightly alkaline range. Suspended-sediment concentrations are somewhat higher in the Carbon River (station 1Q) than in South Prairie or Wilkeson Creeks (stations 2Q and 4Q) because the Carbon River carries glacial silt. For example, of nine samples taken during 1955 from the Carbon River and South Prairie Creek (U.S. Geological Survey, 1959), the mean suspended-sediment concentration in the glacially fed Carbon River was 85 mg/L while that in the nonglacial South Prairie Creek was 17 mg/L. However, even the greatest sediment concentration measured in the Carbon River in 1955 (283 mg/L) is far less than concentrations found in recycled water systems of many hydraulic coal mines (Cooley, 1975, p. 5-31).

The quality of water in Wilkeson and South Prairie Creeks is expected to be similar since they drain areas similar in geology and topography and neither is fed by glacial melt waters. Both contain water with low dissolved-solids content and with neutral to slightly alkaline pH. The maximum suspended-sediment concentration recorded in nine samples taken from South Prairie Creek in 1955 was 113 mg/L (U.S. Geological Survey, 1959) and the maximum recorded in nine samples from Wilkeson Creek during 1976-77 was 16 mg/L. Chemical analyses of water at three sites along Wilkeson Creek and its tributaries are included in table 3. Data from South Prairie Creek at Crocker (station 3Q, fig. 1) represents the quality of the combined waters from Carbon River, South Prairie Creek, and Wilkeson Creek.

From the foregoing analyses, the quality of the water in the three streams appears to be satisfactory for use in the hydraulic mining of coal.

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Quality of ground water draining from mines.--Drainage from abandoned coal mines in the Wilkeson-Carbonado mining district has been sampled and analyzed only at the Skookum mine area near Wilkeson (station 5Q, fig. 1, and enlarged view in fig. 6). Chemical analyses of water discharged from three sampling points at the mines is presented in table 3. Water taken at Skookum area sampling point 8 is a combination of drainage from all mine discharges in the immediate vicinity. During 7 months of sampling at 30-day intervals, the pH of the water discharged at stations 1 through 8 was consistently neutral to slightly alkaline and the acidities were consistently low. The low acidity and neutral pH is due chiefly to the low sulfur content of the coals mined (Beikman, 1961). The heavy-metals in these discharges were all below the safe-limit concentrations set by the U.S. Environmental Protection Agency (1973) for freshwater aquatic life.

Two known water-quality problems are associated with the Skookum mine area drainage: (1) the dissolved-sulfide content in water being discharged from sample point 1 at the Skookum Slope, and (2) the local precipitation of ferric hydroxide. Regarding the dissolved-sulfide content, water from the sealed mine is under reducing conditions and contains appreciable sulfide (10.6 mg/L) in the form of hydrosulfide (HS^-) and undissociated hydrogen sulfide (H_2S). However, by the time this water cascades over rocks to station 8 about 100 feet distant, the sulfide content has been reduced to less than 0.1 mg/L. This leads to the inference that simple aeration can reduce the sulfide concentration of the mine water to levels acceptable for discharging to Wilkeson Creek (U.S. Environmental Protection Agency, 1976), and that no serious water-disposal problems would be encountered by reentry of the mine.

The precipitation of ferric hydroxide is associated with the unsealed gangway draining at the Skookum area fanhouse (sample point 2) and at sample points 4 and 5. If this mine were reentered, the small amount of iron contained in the drainage could be flocculated with chemicals in a settling pond. No extra expense would be incurred because a flocculation process and the settling pond probably would also be needed in the water-recycling system generally used with the hyraulic mining process.

Potential changes in quality.--The present effect of Skookum area mine drainage on Wilkeson Creek can be estimated by noting the change in water quality between the sampling stations upstream from the mine (Wilkeson Creek at Snell Lake Road at Wilkeson, station 6Q, fig. 1; same as upper station, fig. 6) and the sampling station downstream from the mine (Wilkeson Creek near schoolhouse at Wilkeson, station 4Q, fig. 1; same as lower station, fig. 6). Data indicate that water at the downstream station has been completely mixed by the time it reaches this point. The net water-quality change across the mine-drainage reach during the two low flows tabulated in table 3 includes (1) an approximate 35-40 percent increase in common dissolved constituents (calcium, magnesium, sodium, bicarbonate, and sulfate); and (2) a small increase in actual micrograms per liter of total iron and dissolved manganese. All dissolved and total concentrations measured at the downstream site are below safe-limit concentrations set for aquatic life by the U.S. Environmental Protection Agency (1973).

In 1976, the U.S. Bureau of Mines sponsored a borehole hydraulic-mining test at station 7Q near Wilkeson (fig. 1). Water-quality data gathered at the test site by the U.S. Geological Survey indicate that water used in the mining process (Gale Creek at borehole test site, table 3) was changed in the following ways:

1. A large increase occurred in suspended-sediment concentrations, from 10 mg/L to an average of 8,960 mg/L (Borehole Test Slurry 1 and 2, table 3).

2. pH increased from 7.1 to an average of 7.7.

3. Total dissolved solids increased from 50 mg/L to an average 81 mg/L.

4. Water temperature increased from 11.4° to 14.0°C. The water used was not recycled.
5. Dissolved-cadmium and total-iron concentrations increased to levels that could be harmful to aquatic life in the stream (U.S. Environmental Protection Agency, 1973).

The above noted changes are instructive because they indicate the types of problems which might be encountered by other kinds of hydraulic mining in the Wilkeson area. The increased suspended-sediment and metals concentration listed in items 1 and 5 above probably could be controlled by adding chemical flocculants in a settling-pond system. The temperature increase noted might be even greater if water is recycled. If any water temperature problem were to exist, it would be associated with the release of large volumes of warm water to adjacent streams during the low flows of the fall fish-spawning season. Solutions to this problem include (1)aeration and evaporative cooling and (2) spraying excess warm water onto nearby areas of heavy vegetation, for use by the plants.

Based on data gathered at the borehole test site, some potential exists for water-quality problems associated with hydraulic mining. However, these problems appear to be manageable.

Regulations

Information on requirements for maintaining minimum flows for fish propagation is available from either the State of Washington Department of Game (sports fisheries) or Department of Fisheries (commercial fisheries) in Olympia, Wash. The State of Washington Department of Ecology in Redmond, Wash., also can be contacted for information concerning guidelines on effluent from such a coal-mining project and for an effluent-discharge permit. Such projects are covered under Public Law 92-500, and interim Federal effluent limitations guidelines have been published (U.S. Environmental Protection Agency, 1975) as required by this law.

Future Studies

If one or more specific sites should be selected in the Wilkeson-Carbonado district to test hydraulic mining equipment, several short studies would be appropriate before mining begins to allow for more precise planning of mine operations and a more effective response to environmental concerns of the State of Washington Department of Ecology. The water supply at specific stream sites should be studied so that any needs for water storage could be more accurately evaluated. Coal from the specific seams to be mined should be processed in the laboratory through a soxhlet extractor (Renton and Hidalgo, 1973) to obtain a preliminary assessment of the quality of the drainage that would be associated with mining these seams. Lastly, if mines other than those in the Skookum area are to be reentered, the quality and quantity of discharge from these mines should be analyzed.

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